AD NUMBER

AD850896

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies only; Administrative/Operational Use; NOV 1968. Other requests shall be referred to Naval Civil Engineering Laboratory, Port Hueneme, CA 93041.

AUTHORITY

usncbc ltr, 19 jun 1978

DISCLAIMER NOTICE

THIS DOCUMENT IS BEST QUALITY
PRACTICABLE. THE COPY FURNISHED
TO DTIC CONTAINED A SIGNIFICANT
NUMBER OF PAGES WHICH DO NOT
REPRODUCE LEGIBLY.

ORDNANCE DIVISION

RESEARCH & DEVELOPMENT

FINAL REPORT

PROPELLANT-ACTUATED EMBEDMENT ANCHOR

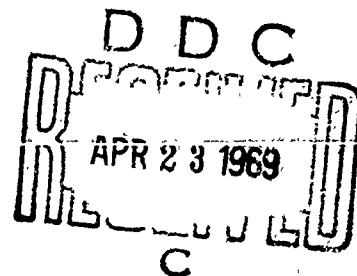Contract No. N62399-68-C-0002

To

U. S. Naval Civil Engineering Laboratory
Port Hueneme, California

Report No. 3324-01(01)FP / November 1968 / Copy 15

CR 69.026

AEROJET GENERAL TIRE **GENERAL** ®

D D C
APR 2 3 1969
C

AEROJET-GENERAL CORPORATION

DOWNEY, CALIFORNIA

AEROJET-GENERAL CORPORATION
Research & Development
11711 Woodruff Avenue
Downey, California 90241

FINAL REPORT

PROPELLANT-ACTUATED EMBEDMENT ANCHOR

For Period August 1967 to November 1968

To

U. S. Naval Civil Engineering Laboratory
Port Hueneme, California
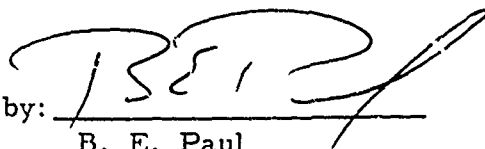
November 1968

Prepared by: _R. A. Thomason_ Approved by: _B. E. Paul_
R. A. Thomason   B. E. Paul
NCEL Anchor   NCEL Anchor
Project Engineer   Program Manager

F. J. Buccella
F. J. Buccella

E. I. Lindberg
E. I. Lindberg

ABSTRACT

This report contains a review of the results of an engineering, development, and manufacturing program for the development of a propellant-actuated embedment anchor. The objective of the program was to provide a prototype anchor system suitable for marine salvage operations. Calculations and engineering discussions are presented to support the design concept and certain specific components contained in the system. Test results are reviewed to define the demonstrated performance capability of the anchor in a variety of sea-floor compositions. Numerous photographs and drawings are included to illustrate the various anchor system components and to document the development test operations. Several appendixes are included to define specific test procedures, some of which are applicable to a general, future proof-test and evaluation program.

CONTENTS

iv

CONTENTS (Continued)

FIGURES

FIGURES (Continued)

Section 1

INTRODUCTION AND SUMMARY

This is the final report submitted by the Aerojet-General Corporation in fulfillment of Contract N62399-68-C-0002 with the U. S. Naval Civil Engineering Laboratory (NCEL). The objective of the program was to design, develop, and test a propellant-actuated embedment anchor for marine salvage operations and deep-sea mooring.

The various test operations were conducted at three general locations. Test locations were selected on the bases of desirable sea floor compositions, water depth, current, and surface conditions, as well as support vessel availability and shore support requirements. Sand anchor tests were conducted in the vicinity of the NCEL, Port Hueneme, California; mud anchor tests were conducted at the Hunters Point Naval Shipyard, San Francisco Bay, California; and the coral test operations were conducted in the vicinity of the Naval Ordnance Unit, Key West, Florida. Tests were conducted from such surface support vessels as were available with respect to time and the location of each individual test firing.

In developing the propellant-actuated embedment anchor, much that has previously been accomplished was retraced, but with considerable gain in overall capability and reliability. Essentially, what is new in the current embedment anchor system are the avoidance of anchor projectile penetration problems in all sea floor mediums and the development of an anchor for use in coral. The range of analytical engineering in the areas of internal ballistics, structures analysis, and penetration dynamics has been considerably extended beyond what is found in open literature so that almost any contingency can be dealt with as regards fluke design, launch vehicle design, propulsion system, including propellant, booster and ignition subsystem concepts, and the size and configuration of down-haul cables.

The ultimate goal is a range of anchor sizes suitable for offshore salvage operations as well as for diverse utilization in all areas of marine construction and engineering. The conditions imposed on such operations by the large variety of sea-floor compositions, such as sediment over basalt, present the final engineering problems yet to be solved.

The design of an embedment anchor suitable for such diverse applications has engaged the attention of Government agencies and private enterprise for the last decade. The design configuration of the Aerojet anchor remains

1

unique, however, with respect to the three-fluke projectile arrangement and the inverted barrel/reaction vessel geometry. A prototype anchor system is shown in Figure 1-1.

The success of the overall system demonstrates Aerojet's ability to develop exact solutions to various problems of embedment anchor mooring system design, within the limits of the accuracy of data defining sea-floor properties, in a form suitable for future application to embedment anchor requirements.
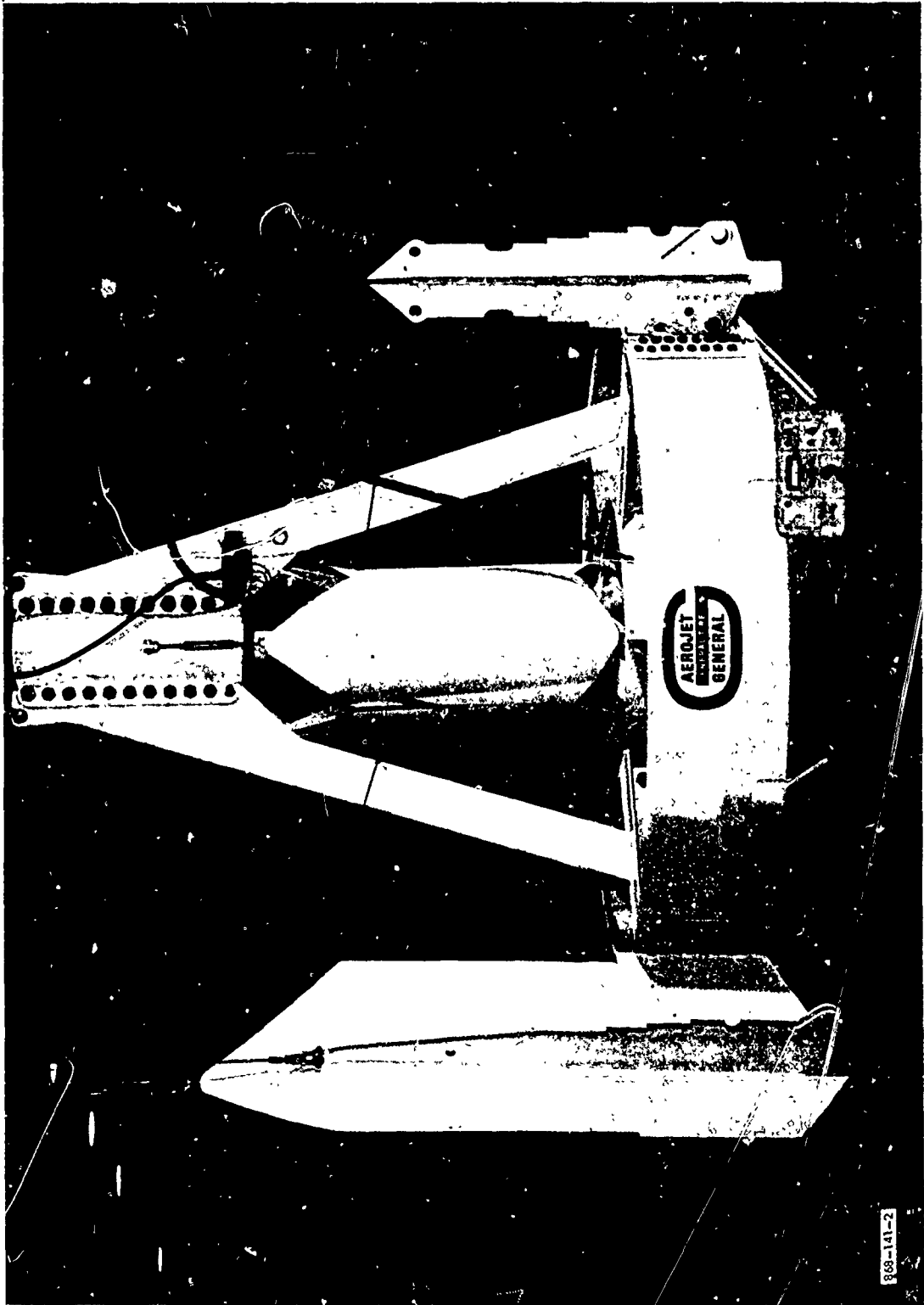
Figure 1-1. Prototype Anchor System.

Section 2

DESIGN APPROACH

In the U. S. Navy Publication Ship Salvage Notes, a textbook of the Deep Sea Diving School, U. S. Naval Weapons Plant, Washington, D. C., it is noted that, "No set rules or procedures can be followed in working out a salvage problem. Time is precious, facilities limited, and all problems differ. Such conditions have clearly necessitated a continuous reappraisal of salvage techniques and equipment."

The rigging operation for a single-point moor using conventional drag anchors and beach gear will take from 1 to 6 hr, depending on the amount of equipment used, which in turn depends on the salvage task, water depth, characteristics of the bottom, and prevailing sea state conditions. The overall development of the propellant-actuated embedment anchor system has been guided by such time-oriented utilization characteristics. Accordingly, the detail operational and design requirements that have guided the development of the anchor throughout the course of the program are briefly discussed in the following paragraphs.

The anchor system must be capable of providing a fixed mooring point on the sea floor by embedding the anchor. Because of the virtually infinite variety of sea-floor compositions that exist throughout the world, it was necessary to reduce the classification of sediments to a few fundamental constituent elements. These elements were defined throughout the program as "baseline materials." Baseline materials are defined as (1) specific sediment whose predominant constituent element is a specific sand, (2) a sediment with a predominantly silt and clay composition, and (3) a consolidated coral element. All penetration and holding power calculations were predicated on the baseline compositions.

It was required that the anchor have a working load holding capacity of 160,000-lb horizontal force measured at the towing vessel for a period of up to 8 days. It was also required that the anchor be capable of developing a proof-load holding capability of 200,000-lb horizontal force on the hawser at the surface support vessel for a short period of time. Throughout the development program, pull-test loads were measured at the point of attachment between the ship and towing hawser. A Navy-furnished load cell was utilized for all tests.

5

As a design requirement, the anchor system was required to operate in a water depth of 50 to 500 ft. The anchor system also had to be "deck safe" and provide an arm/disarm characteristic that would function in not less than 30 nor more than 40 ft of water. This concept governed the design to the extent that only two pressure sealing O-rings were utilized throughout the structure. Consequently, no hydrostatic sealing problems were experienced in development operations. With respect to shallow water operational characteristics, the anchor functioned without difficulty in 30 ft of water.

The anchor was designed to be suitable for operational use from ATF, ARS, ASR, and ATS Class vessels. Consequently, the design configuration envelope was limited to a maximum gross weight of 12,000 lb, an overall height of 12 ft, and a maximum diameter of 10 ft. Anchor tests were conducted aboard both ATF and ARS support vessels, and no unusual rigging, handling, or launching difficulties were experienced.

Other general objectives were to develop an embedment anchor system that would be economically feasible and competitive with alternative methods. This task was reflected in detail design, materials manufacturing processes, assembly procedures, and provision for reusability. To accomplish this end, considerable attention was given to interchangeability of various components. Consequently, both the sand and mud flukes are interchangeable on a single anchor projectile. In addition, the sand/mud projectile and the coral projectile utilize the same piston and shear pin arrangement.

The final design objective was safety. Maximum ordnance safety has been observed throughout the propulsion subsystem design. The safe/arm device provides a manual deck safing pin, nonelectric ordnance trains between the safe/arm device and the explosive bolts as well as the main propulsion charge, electromagnetic filters, and visual checkout equipment as part of the firing apparatus. As part of the safe/arm device, an inclinometer provides orientation information of the anchor on the sea floor.

2.1 DESIGN OBJECTIVES

The design of a propellant-actuated embedment anchor is resolvable into two relatively independent problem areas: (1) the gun design (internal ballistics) of the launch vehicle and (2) projectile penetration dynamics (external ballistics). Structural design of the launch vehicle and anchor projectile is dependent upon both internal and external ballistic requirements, as well as the requirements imposed by the stress of sustained holding loads.

6

The fundamental internal ballistics equations are unified by factors relating propellant grain size, web, granulation, potential energy, weight of the anchor projectile, and maximum allowable acceleration levels, as well as desirable working pressures commensurate with maximum allowable pressures. The general groupings of various mathematical expressions were programmed for computational operations to yield propellant load quantities, projectile velocities, pressure/displacement profiles, and so forth.

The penetration dynamics and holding power predictions of the anchor projectile are dependent upon the mechanical properties of the various sea-floor compositions. For this analysis, three hypothetically pure soil compositions were utilized for baseline design criteria. The compositions considered were media with only cohesionless properties (sand and gravel), solely cohesive properties (silt and clay), and consolidated coral. Various equations relating shatter strength and plastic flow properties with respect to required anchor penetration depth were utilized to determine the necessary striking velocity of the anchor projectile. The ultimate holding power of the embedded anchor projectile was predicted and verified by equations relating the cohesive and/or cohesionless strength, as applicable (a measure of the ultimate bearing capacity of the material), with respect to such anchor design parameters as embedment depth, fluke bearing area, and fluke shear perimeter. The final numerical accuracy of penetration and holding power prediction results depended, of course, upon the accuracy with which the sediment constant properties were estimated.

It is therefore necessary to point out that the bulk of existing knowledge and data regarding the soil properties is subject to numerous qualifications. Also, there is no standardization of the sediment properties (in fact, many leading authorities oppose standaridzation of some tests), and most soil analyses give numerical results that, at best, are no more than rough estimates. Fair estimates of the few governing properties is all that is needed, however, if the soil physical phenomena associated with those properties and the penetration and holding power mechanism are well understood. Accordingly, substantial effort was spent to analyze various design criteria with respect to sediment properties. Experimental evidence was reviewed, and certain theoretical deductions are presented as fully as practicable.

2.2 STRUCTURAL DESIGN ASPECTS

Structural design of the anchor system may be resolved into four general load-imposing conditions: (1) recoil-induced loads, (2) projectile setback loads, (3) penetration dynamics loads, and (4) holding power loads. The

anchor launch vehicle, which consists principally of the reaction vessel, struts, and gun barrel, was structurally designed for recoil and internal ballistics loads. The anchor projectile was designed to withstand loads imposed by the commuted medium during penetration and loads imposed by the withdrawing forces of holding power tests. To keep the overall anchor structure as light as possible, lightweight sections constructed principally of triple alloy steel were utilized. Shipboard space limitations and handling equipment capabilities determined many of the geometrical design limitations. Other parameters, such as the ratio of projectile weight to frontal area, fluke area, fluke braces, and hinge pins, were governed by penetration and holding power considerations.

2.3 FIRING MECHANISM SUBSYSTEM

In general, the design and development of the firing mechanism followed standard ordnance practices. Two independent ordnance functions were required: (1) initiation of the propellant package in the launch gun and (2) separation of the explosive bolts holding the down-haul cable connector lugs to the reaction vessel. From a safety standpoint, it was stipulated that a safe/arm device be used that could be controlled from a firing panel on the deck of the surface support vessel. With a safe/arm device housing the electric detonators, it was then necessary to simultaneously transmit ignition energy from the safe/arm to the propellant package and the explosive bolts. Mild detonating fuze (MDF) was selected for this purpose. As the name implies, MDF is a detonating fuze capable of transmitting the detonation energy from one place to another in a relatively nondestructive manner. Associated with the MDF are the interfaces where the MDF is attached to the safe/arm device, the main propelling charge, and the explosive bolts.

With the basic firing system defined, the design and development of the firing panel and cable assembly, safe/arm device including inclinometer, propellant package, explosive bolts, and explosive lead subcomponents then took place.

Basically, the firing panel is an electronic control box that provides the necessary power to operate the safe/arm device and the current needed to fire the two electric detonators within the safe/arm device.

The cable assembly transmits the electrical signals between the firing panel and the safe/arm device. Many of the features of the present safe/arm device were patterned after previously designed safe/arm devices.

However, because hydrostatic pressure is utilized to actuate the safe/arm and the unit must be waterproof and withstand the required water pressures, these items had to be considered in the unit design. The basic mechanism of the safe/arm includes an in-line out-of-line slide holding the electric detonators. The slide is locked in the safe position with the detonators out of line with the explosive train by means of a solenoid-operated ball-lock system. Release of the solenoid lock and subsequent hydraulic pressure on a bellows assembly moves the slide so that the detonators are in line with the explosive train and also makes electrical contact with the detonator leads so that the detonators can be initiated.

To determine if the anchor assembly is in an acceptable firing position, an inclinometer switch is included as part of the safe/arm device. This inclinometer component is a mercury switch which is normally open but which is closed when the anchor is tilted more than 30° off the horizontal.

The design of the explosive bolts also followed previous design experience and resulted in development of a standard bolt conforming to military specification but modified to accept an explosive booster charge and with provisions for a specific separation plane. Because most explosive bolts designed to date operate either in air or a vacuum, it was necessary to evaluate the separation characteristics under water.

The design of the explosive leads also required special design considerations to provide waterproof connections that would be easy to install under adverse field conditions. Normal end connectors used on explosive leads for missile destruct systems do not provide the degree of waterproofness that was required in this case. A unique yet relatively simple end connection was devised by utilizing standard tube fittings (Swagelok fittings), slightly modified. These fittings provided a mechanical lock as well as a waterproof seal.

Once the preliminary design of the various components was derived and preliminary tests conducted on various explosive interfaces, the design and development of the subcomponents took place concurrently with the manufacturing of prototype models required for initial prototype tests.

No specific design or manufacturing problems were encountered, and the long lead time involved in procuring some of the components was the only major obstacle. Except for procurement of certain components, all the detail parts of the safe/arm, including the housing, were machined by using conventional equipment.

9

As indicated, preliminary testing was conducted on various interfaces and subcomponents, with successful testing of a mockup ordnance system containing all components and later firing of the entire system as installed on the coral anchor test assembly.

2.4 FUNCTIONAL PERFORMANCE TESTS

Functional performance testing was not limited to penetration and holding power. Dry-land tests were conducted early in the program to evaluate the propulsion subsystem and the internal ballistics of the system under controlled conditions. Internal pressure and resulting barrel stresses were measured and evaluated. As the program progressed, stress loads in various structural members were measured and evaluated by using strain gage measuring techniques under hydrodynamic conditions. Penetration of the embedded projectile was measured whenever possible, while the anchor holding power was measured with a Navy-furnished load cell.

Test firing was accomplished on command by an electrical power source from the surface support vessel. In the early tests, the propulsion system was somewhat reduced in size, then incrementally increased until suitable penetration or structural stress established the upper limit. Pull-test loads were applied wherever possible on a 30° angle with respect to the sea floor.

Sustained loads on the order of 100,000 lb and surge loads of 130,000 lb were experienced in sand composition. Down-haul cable failure was the factor limiting greater holding power. Sustained loads of 92,000 lb were experienced in mud composition. Surge loads in excess of 100,000 lb again caused down-haul cable failure. The anchor system was rerigged with heavier cable and an improved equalizing load bridle before the coral tests.

Consequently, the coral configuration anchor withstood sustained loads of 128,000 lb for an extended period and surge loads as great as 136,000 lb, at a scope of 4.5 to 1.0. The anchor could not be freed in this mode of loading. A vertical load of 35,000 to 40,000 lb applied vertically for approximately 10 hr was required to free the coral projectile.

2.5 MANUFACTURING

Virtually all hardware manufacturing was accomplished at Aerojet's Fuller-
ton facility. The only exceptions were heat-treat operations on large sub-
assemblies and gun drilling of the barrel. All fitting, welding, and subas-
sembly operations were carried out in-house. Because of the low production
runs of deliverable hardware, use of specialized tooling was kept to a mini-
mum. Only expendable jigs, fixtures, and shop-aid equipment were uti-
lized to ensure maximum interchangeability. Rough machine work was
accomplished when required before heat treatment; final machine opera-
tions were accomplished after heat treatment. All mating parts were
subjected to quality control inspection to ensure full compliance with the
appropriate drawings and specifications. No unusual fabrication or assembly
problems were experienced during the manufacturing program.

2.6   SEA-FLOOR COMPOSITIONS

Three main categories of sea-floor compositions were distinguished for
analytical consideration: (1) sand, (2) mud (silt and clay), and (3) con-
solidated coral. The various mud compositions are said to be cohesive,
whereas sand and coral are cohesionless.

Cohesion, or cohesive strength, is a general term given to the shearing
strength that a sediment may possess by virtue of its intrinsic pressure
and is therefore independent of the force applied by the anchor flukes. In
the cohesionless composition of sand and the rigid structure of coral, the
shearing strength is the result of friction (which includes rolling and sliding
friction as well as grain interlocking) and is therefore dependent upon the
maximum force and shear perimeter applied by the embedded flukes.

The foregoing classification, although useful for a fundamental appreciation
of the sediment phenomenon (Figure 2-1), is incomplete for embedment
anchor design. Numerous, detailed classification systems are in existence,
but for classifications to be useful, they must be based on the properties
that are important to the problem under consideration.

The U. S. Bureau of Soils modified classification chart (Table 2-1), which
is based on grain size, and the U. S. Bureau of Soils triangular classifica-
tion (Figure 2-2) were utilized in conjunction with numerical values of
sediment properties affecting the holding power of the anchor as described
in Equations 1 and 2, considered under Paragraph 2.7.

11

COHESIVE SOIL

COHESIONLESS SOIL

USUAL TYPE OF SEDIMENT
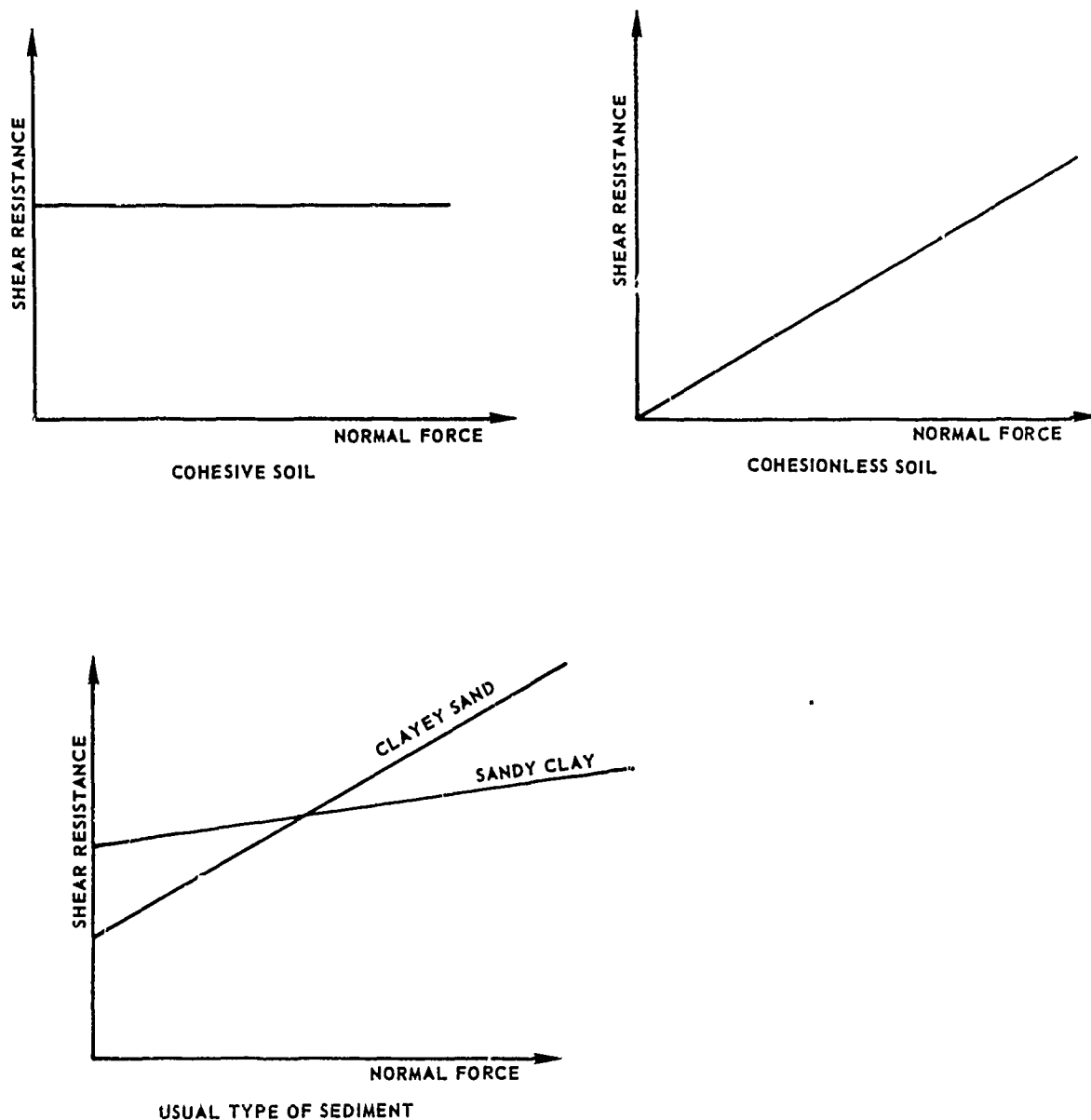
NOTE: IN REALITY, MOST SEDIMENTS ARE COMPOSED OF A MIXTURE OF
COHESIVE AND COHESIONLESS PARTICLES AND ARE OFTEN REFERRED
TO AS SANDY CLAY OR CLAYEY SAND, DEPENDING ON THE PREDOMINANCE OF
ONE OR THE OTHER.

Figure 2-1. Fundamental Soil Types.

Table 2-1. U. S. Bureau of Soils Classification Modified to Relate to Anchor Holding Power.

Condition	Property	Grain Size (mm)						
		Fine Gravel	Coarse Sand	Sand	Fine Sand	Very Fine Sand	Silt	Clay
		2.0 — 1.0	1.0 — 0.5	0.5 — 0.25	0.25 — 0.10	0.10 — 0.05	0.05 — 0.005	0.005
Submerged	c (psf)	0					50 – 150	100 – 500
	τ (pcf)	60 – 105			45 – 70		35 – 50	20 – 45
	C_l	0.2 – 0.5			0.2 – 0.4		0.1 – 0.2	0 – 0.1
Saturated	c (psf)	0		200			50 – 150	100 – 500
	τ (pcf)	120 – 170		105 – 130			95 – 110	80 – 95
	C_l	0.2 – 0.5		0.2 – 0.4			0.1 – 0.2	0
Moist	c (psf)	200 / 600		200			200 – 400	300 – 1000
	τ (pcf)	110 – 140		100 – 115			80 – 100	70 – 90
	C_l	0.4 – 0.8		0.4 – 0.5			0.1 – 0.3	0 – 0.2
Dry	c (psf)	0					50 – 100	100 – 300
	τ (pcf)	100 – 130		90 – 105			50 – 100	0
	C_l	0.6 – 1.0		0.4 – 0.8			0.2 – 0.4	0 – 0.4

13
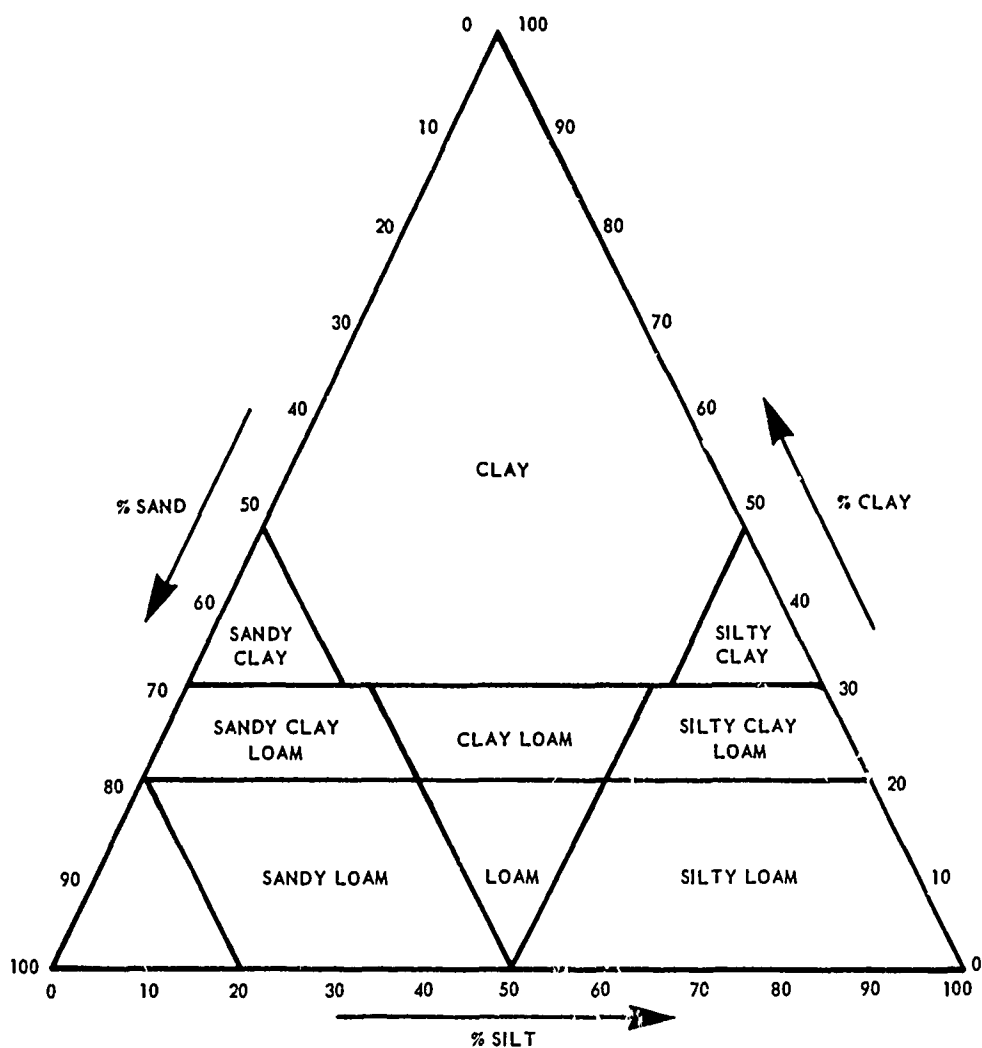
Figure 2-2.   U. S. Bureau of Soils Triangular Sediments
Classification Chart.

3129-AL-1-1

14

To begin the anchor design, considerable effort was directed toward establishing fundamental physical criteria that would define the sea-floor composition baseline properties to be utilized for fluke area and shear perimeter design. Only sand and mud were considered early in the program. Coral formations, evaluated as the program progressed, are discussed in Paragraph 2.7.3. The assumptions made concerning sand and mud are presented in the following paragraphs.

To be considered basic, the sand and mud sediments had to exhibit the following composition range, as defined by the RFP and further outlined by Table 2-1:

Sediment	Composition (%)
Sand	80 to 100
Silt	0 to 20
Clay	0 to 20

Sand may range from "very fine" (0.05 to 0.10 mm in diameter) to "coarse" (0.50 to 1.00 mm in diameter), and still be classified as sand. For this analysis, the baseline sand constituent of the total sediment composition was considered to be made up of the following:

Elements	Diameter (mm)	Composition (%)
Fine gravel	1.0 to 2.0	4.0
Coarse sand	0.5 to 1.0	5.0
Medium sand	0.25 to 0.5	73.0
Fine sand	0.10 to 0.25	15.0
Very fine sand	0.05 to 0.10	3.0
		100.0

Further, it may be seen in Table 2-1 that sand has a characteristic submerged bulk density (SBD), $\bar{\gamma}$, ranging from 45.0 to 105.0 pcf, silt from 35.0 to 50.0 pcf, and clay from 20.0 to 45.0 pcf. The average properties shown in Table 2-3 were derived from Table 2-2.

For a submerged bulk density ($\bar{\gamma}$) of 91.42 pcf, ϕ (Figure 2-3) ranges from approximately 21° to 47°. Therefore, the average value for ϕ is 34°. The mean ϕ value (Figure 2-3) for uniform angular grains at $\bar{\gamma}$ = 91.42 pcf is approximately 36°. Therefore, for ϕ = 36° 1/2 N_γ = 40.0 and N_q = 70.0.

The mud considered as the baseline composition consisted primarily of silt and clay. By definition, silt is comprised of individual particles between 0.005 and 0.05 mm in diameter. Clay particles are defined as being less than 0.005 mm in diameter. For this analysis, the mud constituent of the total sediment composition was considered to be made up of the following:

Mud Elements	Diameter (mm)	Composition (%)
Silt	0.05 to 0.005	65.0
Clay	>0.005	35.0
		100.0

Further, by definition, mud has a characteristic submerged bulk density ($\bar{\gamma}$) ranging from 20.0 to 50.0 pcf, silt from 35 to 50 pcf, and clay from 20 to 45 pcf. Table 2-4 is an outline of submerged properties utilized for this analysis.

For a submerged mud bulk density ($\bar{\gamma}$) of 38.85 pcf, ϕ ranges from 0° to 16°. It was assumed for this analysis that ϕ will have a mean value of 8.0° for uniform round grains. Therefore, from Figure 2-3, if ϕ = 8°, 1/2 N_γ = 0, and N_q = 3.0.

For a submerged bulk density $\bar{\gamma}$ of 36.15 psf, ϕ ranges from 0° to 14°. It was further assumed for this analysis that ϕ will have a mean value of 7°. Therefore, from Figure 2-3, 1/2 N_γ = 0 and N_q = 3.0.

16

Table 2-2. Sediment Composition.

Element	$\bar{\gamma}$ (pcf)	$\bar{c}$ (psf)	$\bar{c}_1$ (Coefficient)
Sand			
Coarse	93.0	0	0.39
Medium	101.0	0	0.47
Fine	54.0	0	0.267
Very fine	66.0	0	0.367
Silt	42.0	100	0.15
Clay	33.0	300	0.05
Fine gravel	74.0	0	0.28

Table 2-3. Submerged Sediment Values by Volume.

Element	Composition (%)	$\bar{\gamma}$ (pcf)	c (psf)	c_1
Sand	96.0			
Coarse	5.0	4.65	0	0.020
Medium	73.0	73.73	0	0.343
Fine	15.0	8.10	0	0.040
Very fine	3.0	1.98	0	0.011
Fine gravel	4.0	2.96	0	0.011
Nominal value	100.0	91.42	0	0.425
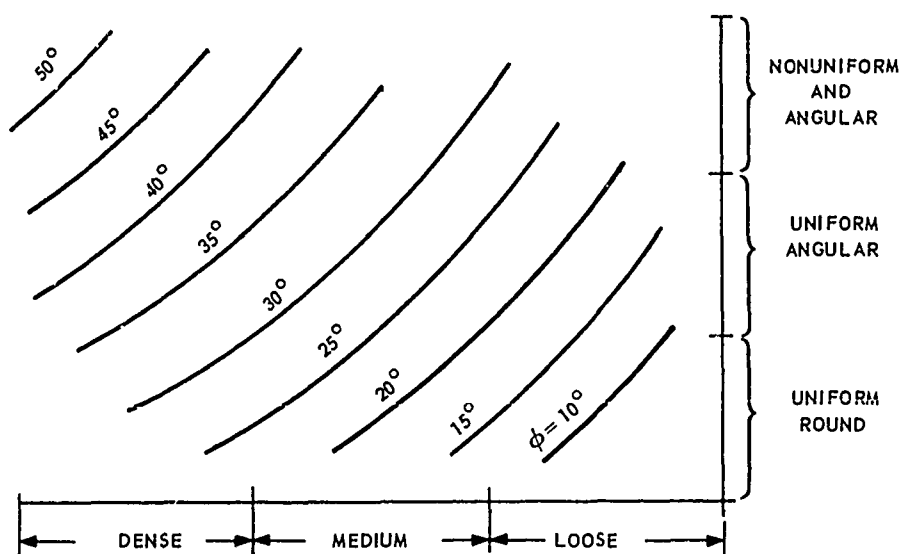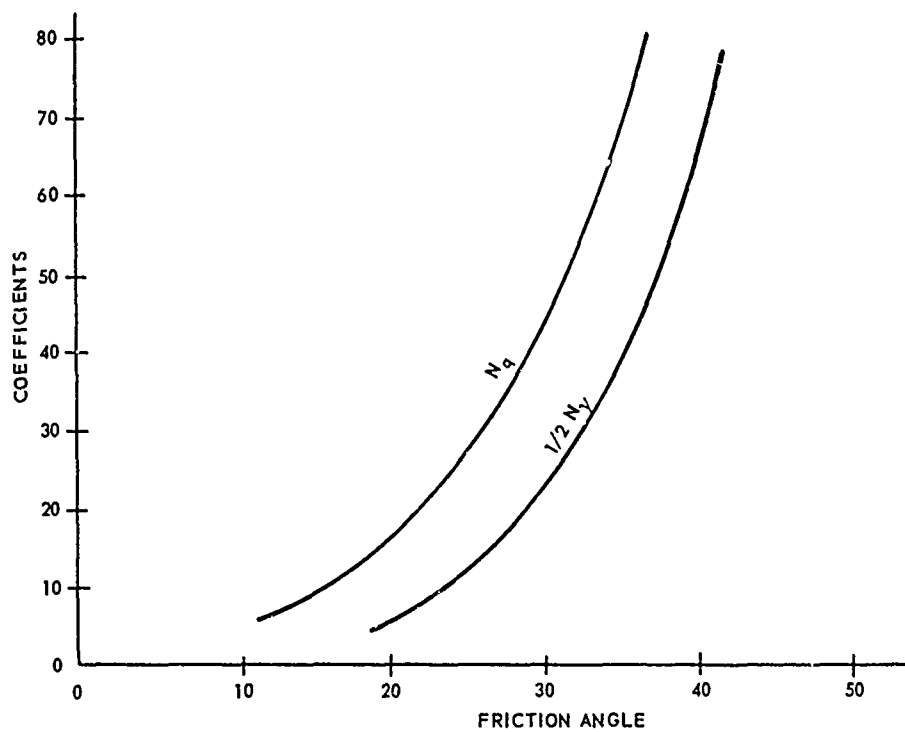
Figure 2-3. Bearing Capacity Coefficients and Friction
Angle for Cohesionless Sand.

Table 2-4. Submerged Sediment Values by Volume.

Element	Composition (%)	$\bar{\gamma}$ (pcf)	c (psf)	c_1
Silt	65	27. 30	65. 0	0. 098
Clay	35	11. 55	105. 0	0. 018
Nominal value (1)	100	38. 85	170. 0	0. 116
Silt	35	14. 70	35. 0	0. 053
Clay	65	21. 45	195. 0	0. 033
Nominal value (2)	100	36. 15	230. 0	0. 086

2.7 HOLDING POWER AND PENETRATION

2.7.1 Holding Power of the Anchor in a Cohesive Medium

In a purely cohesive medium, the holding power of the anchor, when sub-
jected to a vertical load that produces no moments, has been described by
the equation

$$H = \bar{\gamma} Z A_e + (144) p A_e + c Z P_E \qquad (1)$$

where

H = the vertical withdrawing load that can be re-
sisted by the anchor (lb)

$\bar{\gamma}$ = average medium unit weight (pcf)

c = cohesive shear strength of the medium (psf)

p = atmospheric pressure on the anchor flukes (psi)

19

A_e = effective anchor fluke area (sq ft)

P_e = effective anchor perimeter (ft)

Z = depth at which flukes have become fully extended (ft)

Equation 1 can be stated as follows: The holding capability of the anchor embedded in a purely cohesive medium is equal to the effective weight of the sediment resting on the effective fluke area, plus the force of atmospheric pressure on the effective fluke area, plus the cohesive shear resistance of the sediment.

Equation 1 is based on the following assumptions:

a. Ultimate failure is caused by shear failure of the medium.

b. Shear failure takes place instantaneously over the entire side surface of the vertical column of sediment resting on a base provided by the extended fluke platform area.

c. The only shear resistance of the sediment results from cohesion, which is uniform in all failure planes.

d. Any air that might be in the sediment pores is virtually sealed off from atmospheric air.

e. The sediment medium is not capable of resisting tension.

None of these assumptions is completely true even in an idealized, purely cohesive, and homogeneous medium. Nevertheless, the equation has its merits. It gives a reasonably complete and easily understood picture of the process of anchor-sediment system failure and constitutes a means of predicting the holding power of the anchor on a logical basis in terms of definite and definable parameters, some of the meanings of which are discussed in the following paragraphs.

2.7.1.1 Unit Weight

The term $\ddot{\gamma} \cdot Z \cdot A_e$ represents the weight of the sediment "supported" by the extended flukes; $\bar{\gamma}$ is the weight per unit volume of the sediment. For a given sediment, $\bar{\gamma}$ will increase with an increase in compactness and

moisture content. For any degree of compactness, $\bar{\gamma}$ attains its maximum value when the sediment is fully saturated. In the special case of a sea-floor medium, the weight carried by the anchor flukes is decreased by buoyancy forces, and the value of $\bar{\gamma}$ used in Equation 1 becomes

$$\bar{\gamma} = \gamma \text{ (buoyant)} = (\gamma_{sat} - 62.4 \text{ pcf})$$

2.7.1.2 Effective Fluke Area

The true effective fluke area (A_e) is always somewhat greater than the actual projected fluke planform area because the sediment shear failure lines are not vertical but spread outward. It appears, however, that the angle at which the shear failure lines are inclined to the vertical diminishes rapidly as the free soil surface is approached. Consequently, Equation 1 omits the "shear failure angle."

2.7.1.3 Atmospheric Pressure Force

The contribution of atmospheric pressure force (p) to the total anchor holding power is dependent upon formation of either a partial or complete vacuum beneath the anchor fluke plane area. There can be little doubt that such a vacuum will exist initially in most cohesive sediments. However, it is equally certain that, given sufficient time, this vacuum will be filled either with water or the commuted sediment itself. The time required for this filling to occur will vary widely with the type and state of sediment.

2.7.1.4 Cohesion C

There are two kinds of cohesion in sediments: (1) true cohesion, which the sediment material may possess by virtue of its intrinsic pressure (mutual attraction of particles resulting from molecular forces), and (2) apparent cohesion resulting from the action of moisture films. For instance dry sand, especially fine sand, is very cohesive when it becomes moist. Surface tension acts at the surface of the film and holds the sand grains together. This type of cohesion is lost when the moisture content becomes excessive, such as near the water/sediment interface. On the other hand, true cohesion tends to persist independently of the moisture content, although the magnitude of true cohesion in actual sediments is usually relatively low (it occurs in clays or clayey substances only, and tends to be

21

greater in densely packed media). A large part of the shear strength
of clay and silt composition results from apparent cohesion. Cohesion may
be developed in any direction within the medium. Normally, materials
possessing shear strength resulting from cohesion will also be able to
offer some resistance in tension. Seemingly, the holding capability of the
anchor in a cohesive medium will be augmented by tension at the bottom of
the flukes. The magnitude of this force is relatively small; Equation 1
omits the force.

2.7.1.5 Depth Z

If atomospheric pressure effects are neglected (the term $p \cdot A_e$), the
holding power of the anchor as expressed by Equation 1 is proportional to
depth Z. However, as H increases, the normal pressure on the medium
(H/A) also increases. Evidently, at some depth H/A, where A is the
actual fluke planform area, the compressive strength of the sediment will
be exceeded, and Equation 1 will cease to apply. After this limiting value
has been attained, further increase in depth alone cannot result in any
appreciable increase in the anchor holding capability because the anchor
will just be "cutting" through the sediment. If, however, the fluke area
and/or shear perimeter is increased, then some further increase in anchor
depth will be advantageous.

2.7.2 Holding Power of the Anchor in a Cohesionless Medium

In a purely cohesionless medium, the holding power of the anchor when
subjected to a vertical pull that produces no moments can be described by
the equation

$$H = \bar{\gamma} \cdot Z \cdot A_e + C_1 \cdot Z^2 \cdot P_e \tag{2}$$

where

C_1 is the dimensionless coefficient related to the frictional shear strength
of the medium. Other symbols have the same meaning as in Equation 1.

Equation 2 can be stated as follows. Holding force equals the effective
weight of the medium resting on the fluke effective area plus maximum
shear resistance resulting from friction.

22

Equation 2 is based on the following assumptions:

a. Failure is caused by shear failure of the medium.

b. Shear failure takes place along the fluke effective perimeter and in a vertical plane.

c. The only shear resistance of the sediment is the result of friction, which includes the interlocking of individual grains.

d. The lateral pressure in a cohesionless medium is proportional to the sediment depth.

It should be noted that assumption a is identical for cohesive and cohesionless media, and assumption b is the same in effect if not in principle. Other assumptions are, of course, different and so are the shear terms in each equation. The shear force component of the holding force in a cohesionless medium is proportional to the unit weight of the sediment $(depth)^2$, the effective perimeter, and a constant C_1. Because any anchor movement (that takes place before the ultimate shear failure of the sand) results in compaction of the medium, C_1 has a value that is never less than 0.4 and probably approaches 0.8 in most cases. In the highly saturated media, the water pressure will tend to reduce C_1 by providing cushioning between the particles, thereby reducing the interlocking effects resulting from coarseness and nonuniformity. Also, it reduces the buoyant unit weight of the sediment. Thus, as in the case of a cohesive medium, the moisture content is the most important single factor affecting the holding power of an anchor. Small amounts of moisture in sand deep beneath the sand/water interface will produce cohesive effects and reduce friction only to a small extent. Large amounts of moisture near the surface of the sand/water interface will cause apparent cohesion to disappear and reduce the frictional shear strength substantially.

2.7.3 Holding Power of the Anchor in Consolidated Coral

In consolidated coral reef compositions, the holding power of the anchor when subjected to a horizontal pull load is described by the equation

$$H = \frac{\sigma \max \cdot A_e}{4} \tag{3}$$

23

σ_{ult} is the ultimate bearing strength of the consolidated coral medium in psf.

Equation 3 is based on the following assumptions:

  a.   Failure is caused by compression failure of the medium.

  b.   The shear resistance of the material is a structural property of an undisturbed, homogeneous composition.

  c.   Medium structural breakup has not occurred as a result of anchor penetration.

  d.   The ultimate bearing strength of the coral is proportional to depth, while the ultimate shear strength is independent of depth.

The holding ability of the coral anchor is achieved through a substantially different medium structural phenomenon than in the case of the sand and mud anchor. It should be recalled that the most significant single factor affecting anchor holding ability in sand and mud compositions is the moisture content. Silt and clay composition (mud) are in a highly plastic state throughout the working range of anchor penetration depth; sand compositions decrease in water content and increase in unit bulk density as sediment depth increases. Coral compositions, on the other hand, are relatively uniform in unit bulk density with respect to reef thickness (depth). The structure porosity remains nearly uniform, and water content is uniform throughout the range of required anchor penetration depths. Beyond very shallow penetration depths, where surface effects are an important factor, the ultimate bearing capacity and shear strength of the coral structure is uniform. In accordance with Equation 3, maximum holding power is obtained at the minimum depth at which surface effects have diminished to insignificant levels. Holding power then becomes directly proportional to the effective projected area of the projectile ribs.

2.7.4   Penetration

The equations of penetration are, by comparison, more clear cut than are the equations that apply to the holding power of the anchor. A full examination of the available technical literature and direct experimental evidence

gained on the program has led to the acceptance of Poncelet's penetration formula. The particular form of Poncelet's equation used for projectile design is

$$Z = \frac{P}{2 \, gi} \ \ln \left(1 + \frac{b}{a} \, V_o^2\right)$$
(4)

where

Z = penetration depth (ft)

P = sectional pressure, W/A (psi); W is the projectile weight in pounds and A is the normal frontal area of the projectile in square inches.

b = the inertia coefficient or constant for the particular material (lb-sec^2/ft^2-in.^{2}).

g = gravitational acceleration in fps.

i = a form factor that is related to the shape of the projectile (usually assumed as 1.0 although the value of 2/3 appears more suitable for the coral projectile).

a = the constant related to the shatter strength of the medium (psi).

V_o = striking velocity (fps).

Equation 4 was applied to all media, including coral. In the usual interpretation, the constant a is a measure of acceleration of the anchor projectile produced by the projectile fracturing the structural framework of the media. The constant b reflects the acceleration of the anchor produced by the reaction motion of the commuted material as it accelerated to velocity V_o. The equation is illustrated in Figures 2-4, 2-5, and 2-6. Figure 2-4 depicts the relationship of anchor weight to frontal area (W/A$_t$) plotted with respect to projectile striking velocity. It should be noted that the required velocity never goes below 100 fps to obtain the required penetration.

Figure 2-5 is a similar relationship wherein the anchor characteristics (W/ZA) are plotted with respect to striking velocity. Again, it may be seen that anchor penetration effectiveness diminishes rapidly as velocity is reduced to 100 fps. Figure 2-6 is the penetration relationship for coral projectiles. In this case, penetration of the coral composition is varied with respect to striking velocity.

25
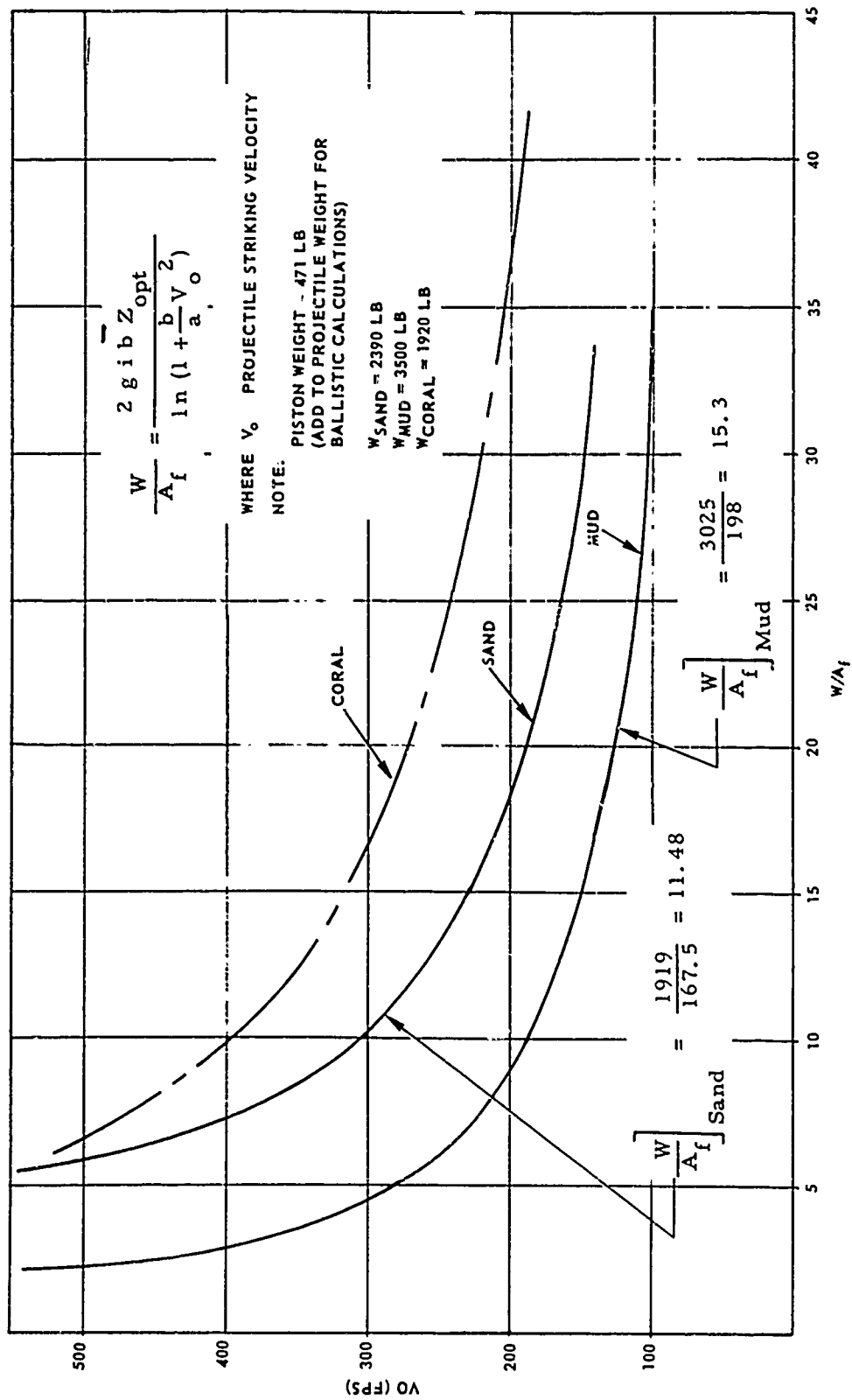
Figure 2-4. Relationship of Anchor Weight to Frontal Area Ratio (W/A_f).

$$\frac{W}{A_f} = \frac{2\,g\,i\,b\,Z_{opt}}{\ln\left(1 + \frac{b}{a}V_o^2\right)}$$

WHERE V_o PROJECTILE STRIKING VELOCITY

NOTE: PISTON WEIGHT - 471 LB
(ADD TO PROJECTILE WEIGHT FOR BALLISTIC CALCULATIONS)

W_{SAND} = 2390 LB
W_{MUD} = 3500 LB
W_{CORAL} = 1920 LB

$$\left[\frac{W}{A_f}\right]_{Sand} = \frac{1919}{167.5} = 11.48$$

$$\left[\frac{W}{A_f}\right]_{Mud} = \frac{3025}{198} = 15.3$$

$$\frac{W}{ZA} = \frac{2\,g\,i\,b}{\ln\left(1 + \frac{b}{a}V_m^{\ 2}\right)}$$

PROPERTY	SAND	MUD	CORAL	CORAL SAND
a (lb/in.^{2})	655	320	830	620
b (lb sec^2/ft^2 in.^{2})	0.0037	0.0020	0.1032	0.0115
i	2/3	2/3	2/3	2/3

CORAL

CORAL SAND

SAND

MUD

Figure 2-5. Penetration Effectiveness.

27

$$\frac{W}{ZA} = \frac{2g\,i\,b}{\ln\left(1 + \frac{b}{a}V_m^{\,2}\right)}$$

$i = 2.3$
$b = 0.0115 \dfrac{LB\text{-}SEC^2}{\mu^2\,IN.^2}$

a = 5000 PSI
a = 4000 PSI
a = 3000 PSI
a = 7000 PSI
a = 1000 PSI
a = 500 PSI

$\dfrac{W}{ZA}$ (LB/FT·IN.²)

V_m (FPS)
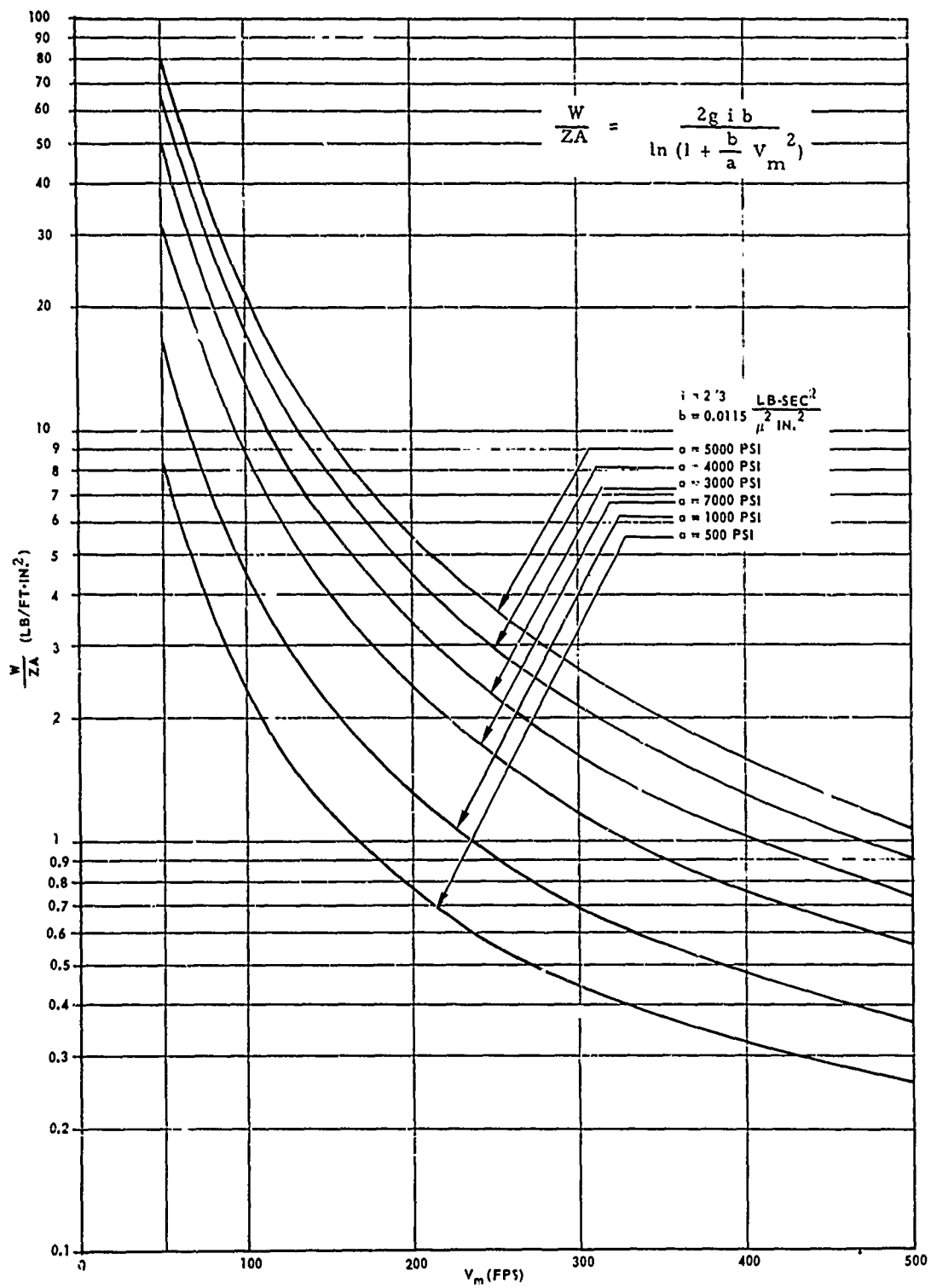
Figure 2-6. Coral Penetration.

28

It was demonstrated on several occasions throughout the test program that the sand configuration anchor would penetrate more than 20 ft into medium sand formations. Penetrations in excess of 30 ft were experienced in silt/clay (mud) sediments. No difficulty was experienced in penetrating consolidated live coral reefs. Penetration into a coral reef to a depth of 11 ft was easily achieved on one occasion. It is concluded that anchor penetration does not represent a design problem and can be ballistically controlled, as well as achieved as required, for any sea-floor compositions in which tests have been conducted thus far.

2.8 BALLISTIC CONSIDERATIONS

The interior ballistic considerations in the anchor design included both analytical and experimental development. The analytical efforts included the assessment of numerous propellants with respect to the mode of combustion, the development of pressure-displacement relationships, the velocity of the anchor projectile as it is accelerated from the launch vehicle, and the design of the gun chamber. Having derived the pressure-displacement curve for the gun, the thickness of the gun wall necessary to withstand the expected pressure at each point was determined by the principles of gun construction. The interior ballistics calculations for the sand, mud, and coral anchors, as well as the fundamental parameters of the gun barrel design, are considered in detail in Appendix A.

A tabulated loading summary is contained in Table 2-5. The final cartridge design is illustrated in Figure 2-7.

Experimental work with respect to the ballistics and charge development was accomplished early in the program at Fort Irwin, near Barstow, California. In this experimental series, three test firings were accomplished. The first test consisted of the fixed barrel (Figures 2-8 and 2-9) and a simulated projectile weighing 2581 lb; 7 lb of M6 propellant was used (Figure 2-10) in the propulsion system. This load produced an internal ballistic pressure of 9430 psi and a muzzle velocity of 161 fps. Projectile velocity was measured as illustrated in Figure 2-8. Here, photoelectric cells and appropriate light sources were placed 12 in. apart at a distance of 3 ft from the gun muzzle. Electrical signals were generated and displayed on appropriate time measurement instrumentation, and the projectile was passed through the light beams. Strain gage No. 1 (Figure 2-9) indicated 700 microstrains at that area, which was equivalent to 2350 psi stress.

29

Table 2-5. Main Propulsion Cartridge.

Propellant Physical Description	Sand Load	Mud Load	Coral Load
Charge Quantity (approximate)	12 lb	6 lb	5.0 lb
Granulation	7 perforation	7 perforation	Ball
Outside Diameter			0.034
Perforation Diameter			-
Length			-
Specification	JAN-P-309	JAN-P-323	Commercial
Web	0.075 in.	0.093 in.	0.034 in.
Type	M-6 Solvent	M-2 Solvent	-
Lot	-	RAD 60326	WC-870

Propellant Composition	Sand, Nominal (%)	Mud, Nominal (%)	Coral, Nominal (%)
Nitrocellulose (13.22)	87.0	75.5	90.0
Nitroglycerin	-	20.0	
Barium Nitrate	-	1.5	
Potassium Nitrate	-	1.0	
Diphenylcamine (add)		0.75	
Dinitrotoluene	10.0	1.0	
Dibutylphthalate	3.0	-	
Graphite	-	0.25	

Igniter Fuze (Common)		Igniter Charge (Common)	
Charge (approximate - gr)	18.0	Charge (approximate - gr)	260.0
Type	Metal clad	Type	Rifle powder
Configuration	Pyrocore	Configuration	Ball
Specification	Commercial	Specification	Commercial
Lot: DuPont	1224	Lot: DuPont	Hi-Vel
		Note: Used with sand and mud cartridge only.	

Detonator/Primer (Common)			
Type	Nonelectric	Number in assembly	2 each
Designation	Mild end primer	Carrier charge (gr)	0.3 RDX
Lot: DuPont	X-310J	Base charge (gr)	3.0 RDX

CARTRIDGE ASSEMBLY
P N 1215305

PRIMER

IGNITER FUZE

PROPELLANT CHARGE

IGNITER CHARGE
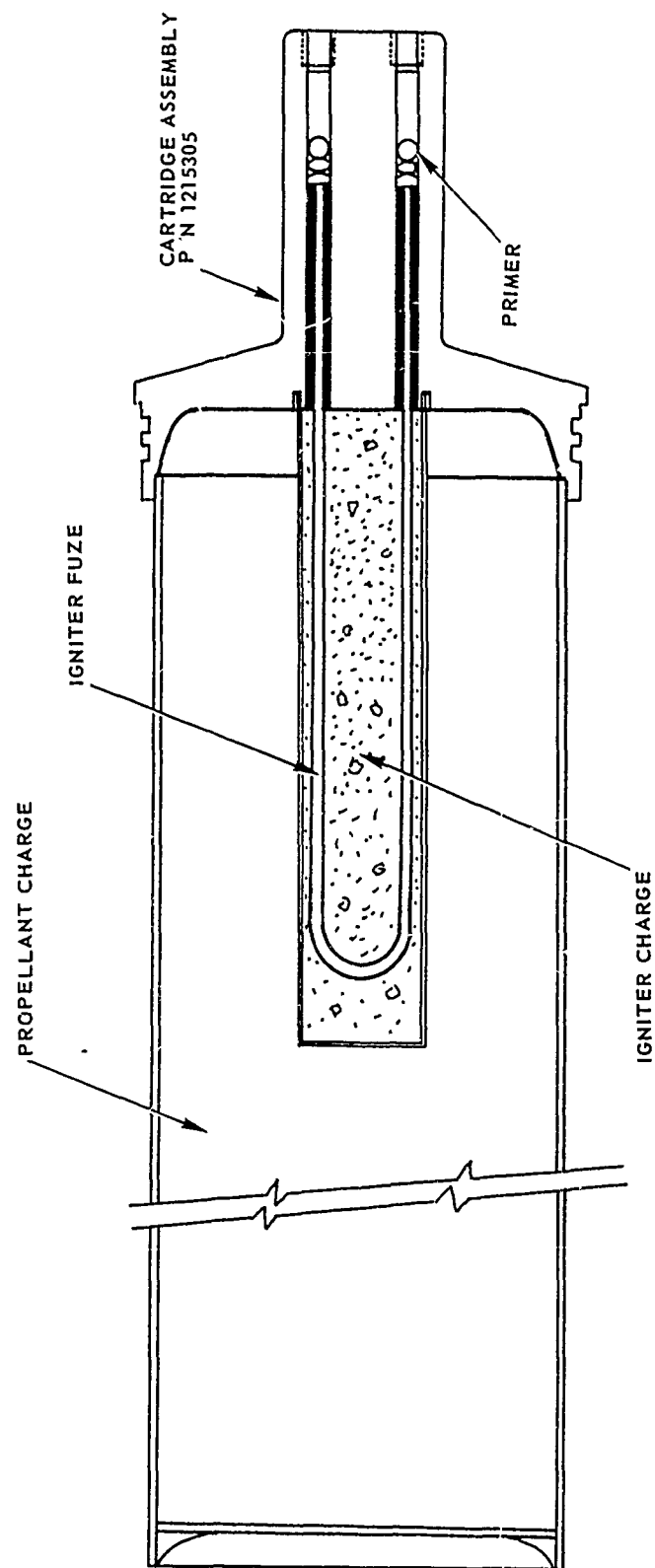
Figure 2-7. Main Propulsion Cartridge.

31
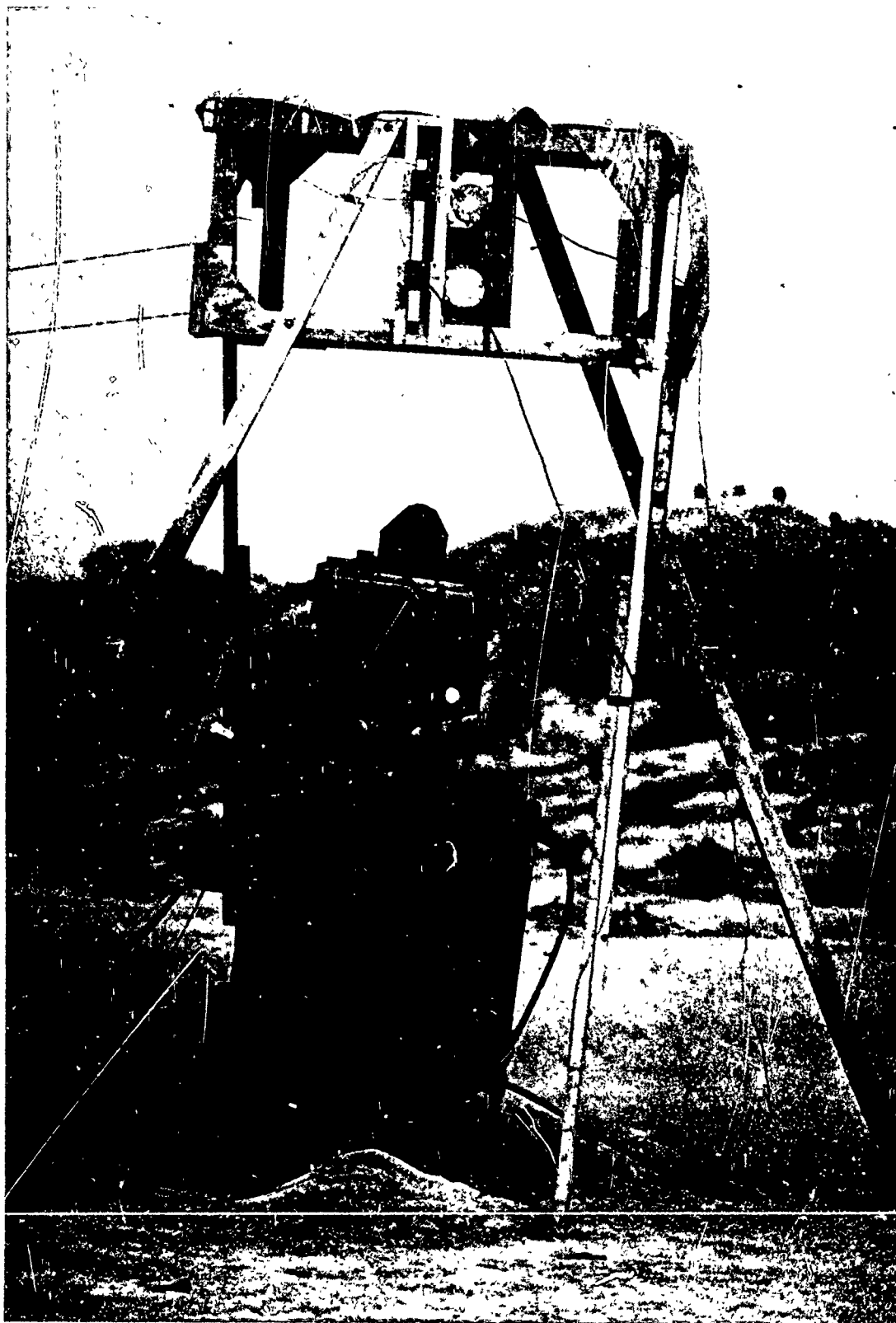
Figure 2-8. Fixed Barrel Test Vehicle.
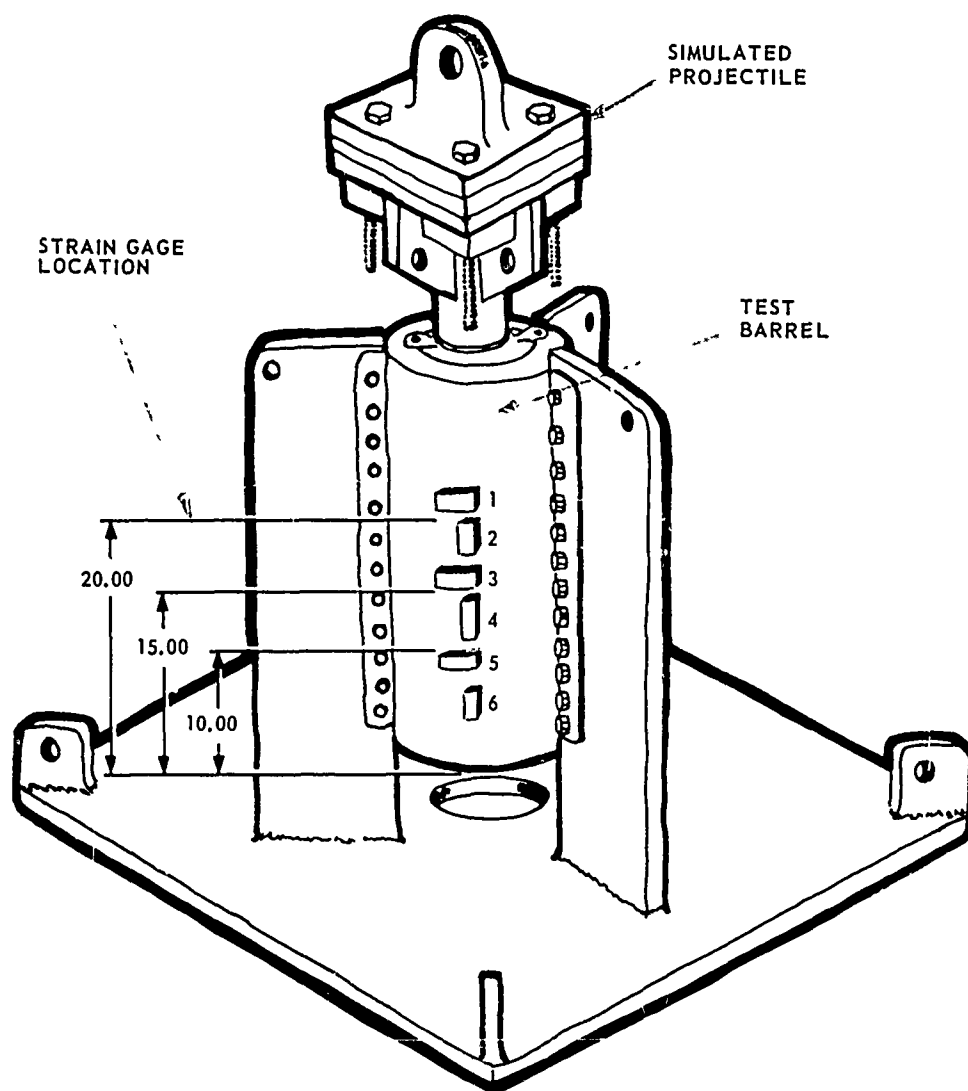
Figure 2-9. Fixed Barrel Test Vehicle.

Figure 2-10.   Test Setup.

34

Test No. 2 consisted of 11 lb of M-6 propellant with the same projectile mass in the fixed barrel assembly. This load produced 13,500 psi internal ballistic pressure, with a muzzle velocity of approximately 228 fps. In this test firing, strain gage No. 1 indicated 1108 microstrains, which was approximately equal to 32,400-psi stress.

Test No. 3 utilized 14 lb of M-6 propellant and produced a muzzle velocity of approximately 350 fps. No ballistic pressure or strain data were obtained because of residual ignition coral fragmentation damage to the instrumentation cables. Figure 2-11 shows the projectile leaving the barrel on test No. 3. This test series indicated the following: (1) the calculated ballistic propellant loads would produce the desired projectile velocity, and (2) the barrel, as designed, could safely handle the pressures produced by the full propellant load under normal operating conditions.

Figure 2-11. Test Firing.

Section 3

STRUCTURAL DESIGN ASPECTS

3.1   GENERAL CONFIGURATION

The completed and assembled anchor was fabricated in accordance with
Aerojet Drawing 1215358 and is shown in Figure 3-1. The anchor consists
of a reusable launch vehicle (Figure 3-2) and an interchangeable projectile
for sand, mud, and coral, as shown in Figure 3-3. The launch vehicle
includes a gun barrel, a reaction vessel, and three connecting struts. The
anchor projectile includes a projectile body, a piston that fits inside the
gun barrel, and three flukes that are interchangeable between sand and mud.
The coral projectile (Figure 3-4) does not require flukes to obtain a holding
capability. Two down-haul cables are connected to the anchor projectile
and to an equalizing bridle. The main mooring hawser is connected to the
equalizing bridle.

3.2   BARREL DESIGN

The barrel assembly, fabricated in accordance with Aerojet Drawing 1215186,
is shown in Figure 3-5. The basic construction was from a forged AISI
4340 steel billet with strut attachment ribs fabricated from AISI 4340 steel
plate. The fundamental stress design was similar to that of a thick-walled
cylinder with internal pressure where the maximum circumferential stress
is at the inner surface. The required outside- to inside-diameter ratio
was calculated from the following equation:

$$\frac{D_o}{D_i} = \sqrt{\frac{3\sigma + 2P_p(1+\epsilon)}{3\sigma - 4P_p(1+\epsilon)}}$$

where

D_o =   outside diameter (OD)

D_i =   inside diameter (ID)

σ =   allowable working stress

P_p =   peak pressure

$1+\epsilon$ =   safety factor

A more detailed analysis of the stress design is discussed in Appendix A.

37
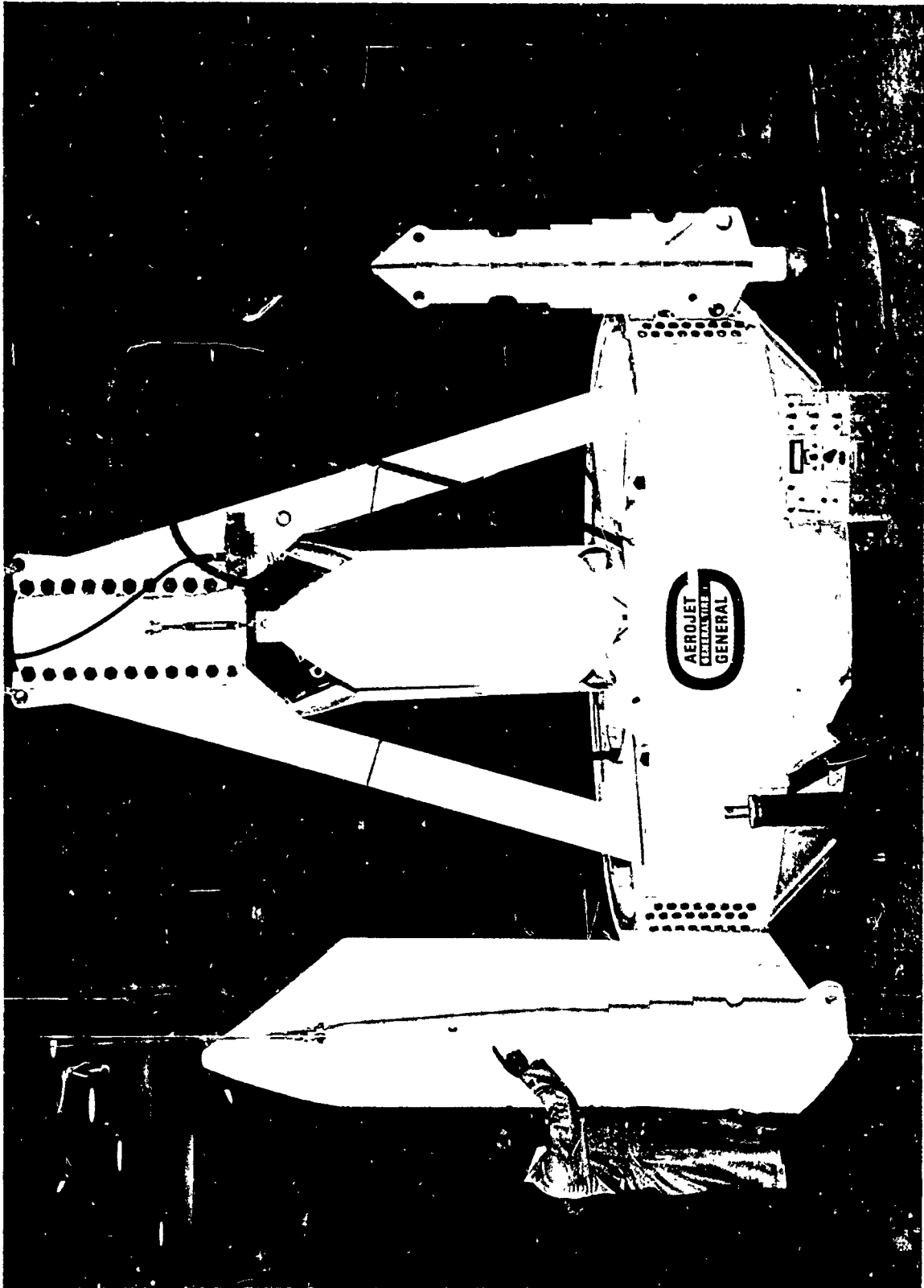
Figure 3-1. Complete Anchor Assembly.
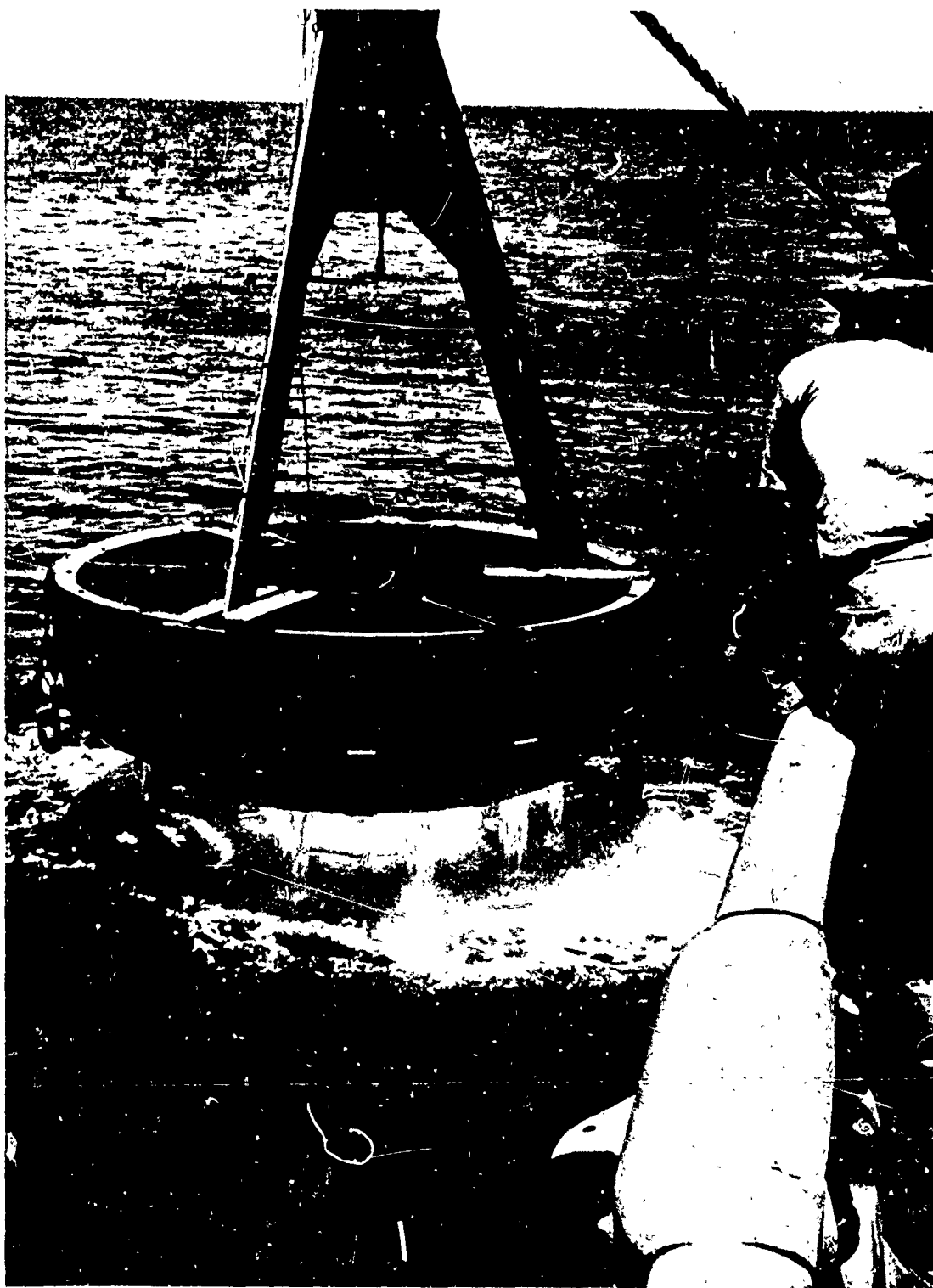
Figure 3-2.   Reusable Launch Vehicle.

Figure 3-3. Interchangeable Projectile.
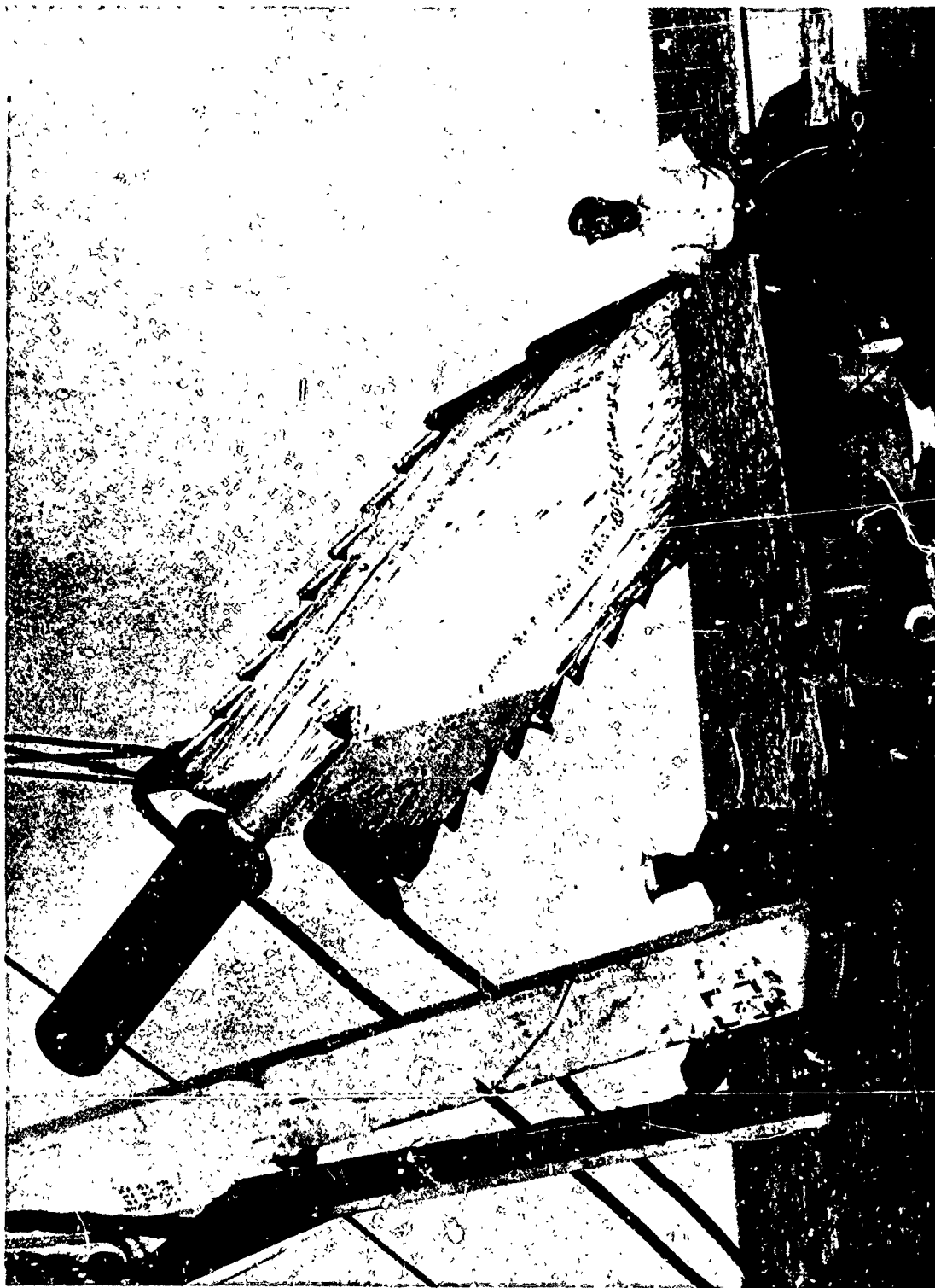
Figure 3-4. Coral Projectile.
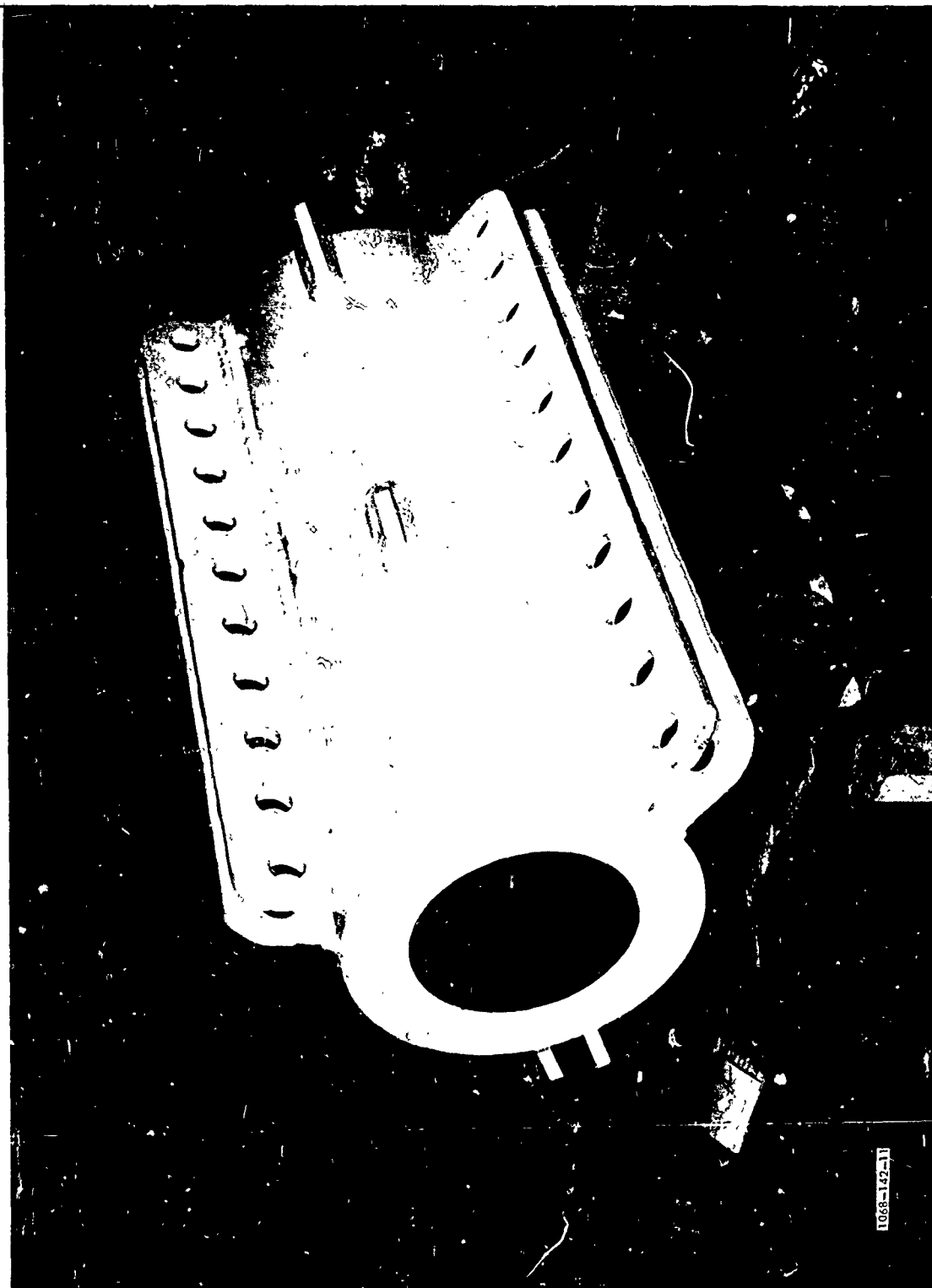
Figure 3-5. Barrel Assembly. (Sheet 1 of 2)

1068—142—11
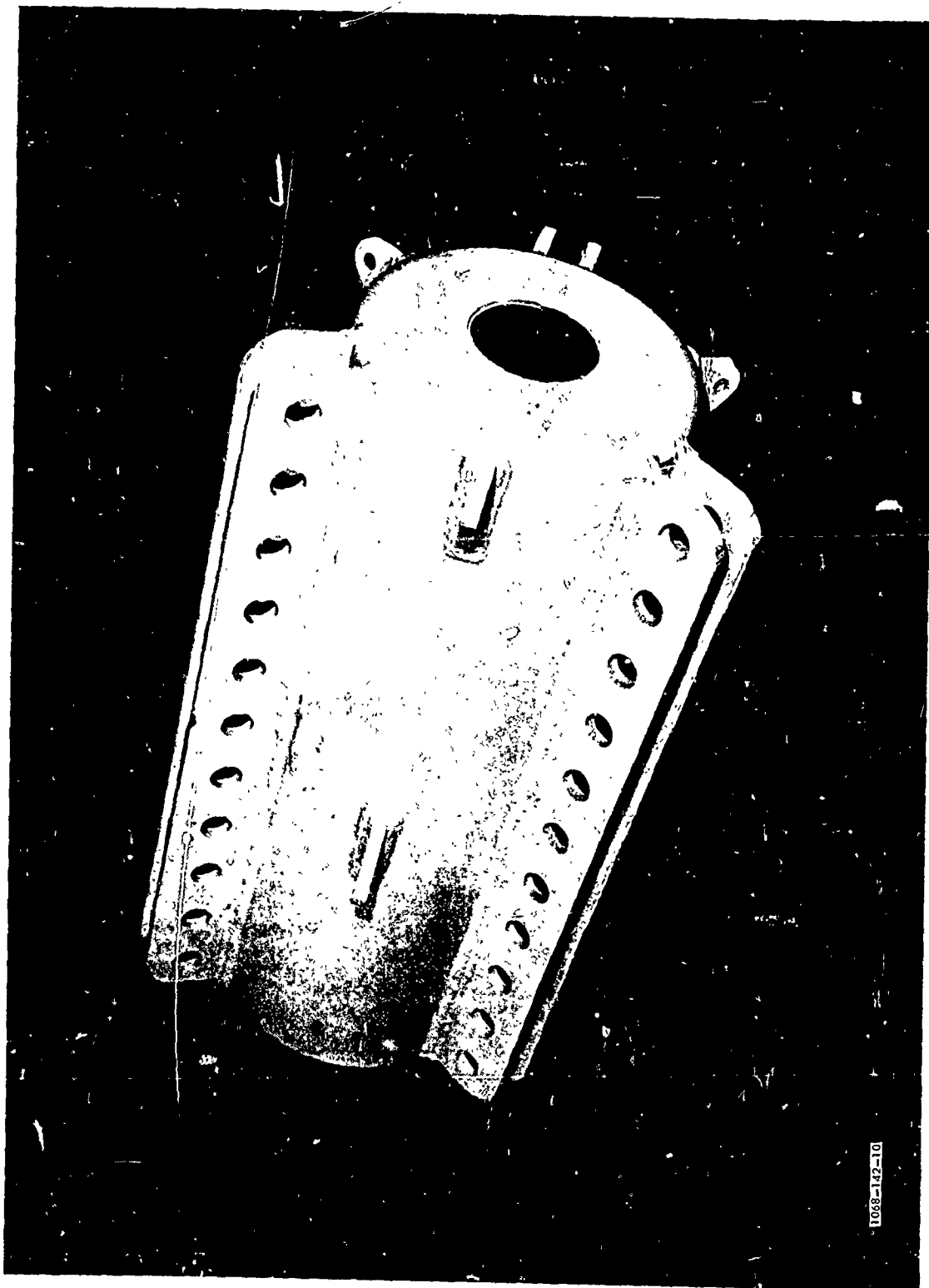
Figure 3-5. Barrel Assembly. (Sheet 2 of 2)

1068-142-10

3.3 REACTION VESSEL DESIGN

The reaction vessel consists of three separate hull assemblies, fabricated in accordance with Aerojet Drawing 1215228. Each hull section is an all-welded structure of 1/2-in.-thick AISI 4340 steel plate. The process of fabrication is shown in Figure 3-6. Completed hull sections are shown in Figure 3-7. The completed reaction vessel assembly, showing strut and barrel installation, is shown in Figure 3-8.

Early in the test program, the reaction vessel test unit experienced deformation and weld joint damage from high ballistic pressure and hydrodynamic pressure loads. Therefore, an additional stiffener bulkhead, perimeter ribs, bottom support frame, and pressure relief holes were added to each hull section. For additional strength, doubler plates were installed at each strut joint as the vessel was assembled. This rework provided the necessary increased strength, and each modification was added to the drawings. After final welding and before machining operations, the welded structure was stress-relieved, normalized, and heat-treated to Rockwell hardness C-32 to 38.

3.4 SAND AND MUD PROJECTILE DESIGN

The sand and mud projectiles, fabricated in accordance with Drawing 1215156, are identical in design. Triple alloy steel is used throughout. Construction consists of three ribs welded to a center shank (Figures 3-9 and 3-10). Down-haul cable hawser attachments are added, and provision for fluke attachment is made. A nearly completed projectile is shown in Figure 3-3.

During the design phase, three types of applied loads were considered: launching setback loads, penetration loads, and holding loads. The design allowable loads for both anchor launch and penetration is 1000 g. The design allowable load from holding power is 100,000 lb for each fluke.

Each down-haul cable is 1-1/2 x 6 x 37 in. IWC wire cable with a breaking strength of 94.5 tons. The loading to each down-haul cable is through a 1-1/2 x 6 x 37 in. IWC wire rope equalizing bridle. The total rigging has a breaking strength of 189.0 tons.

44
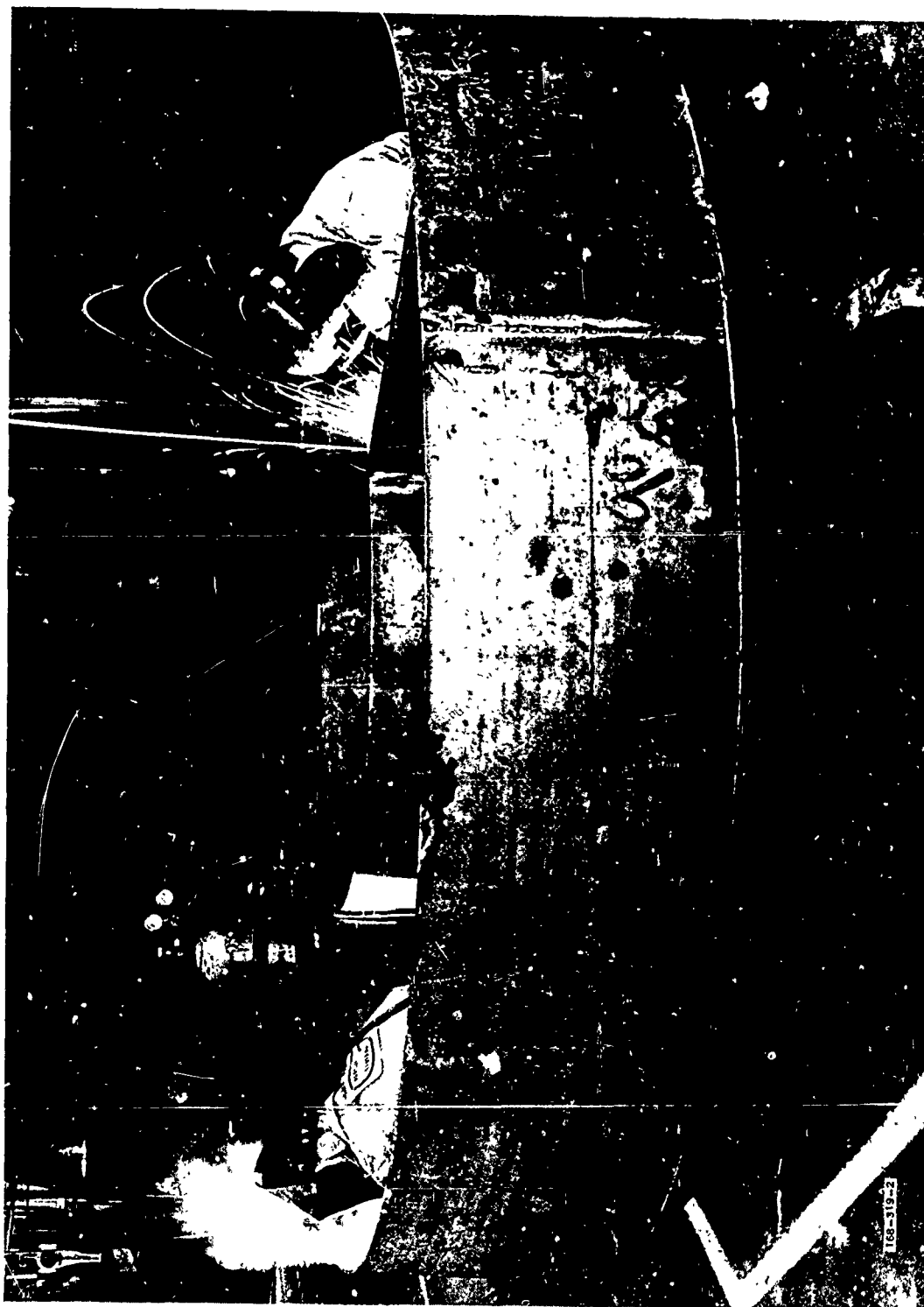
Figure 3-6. Welding of Reaction Vessel.

Figure 3-7. Completed Hull Sections.
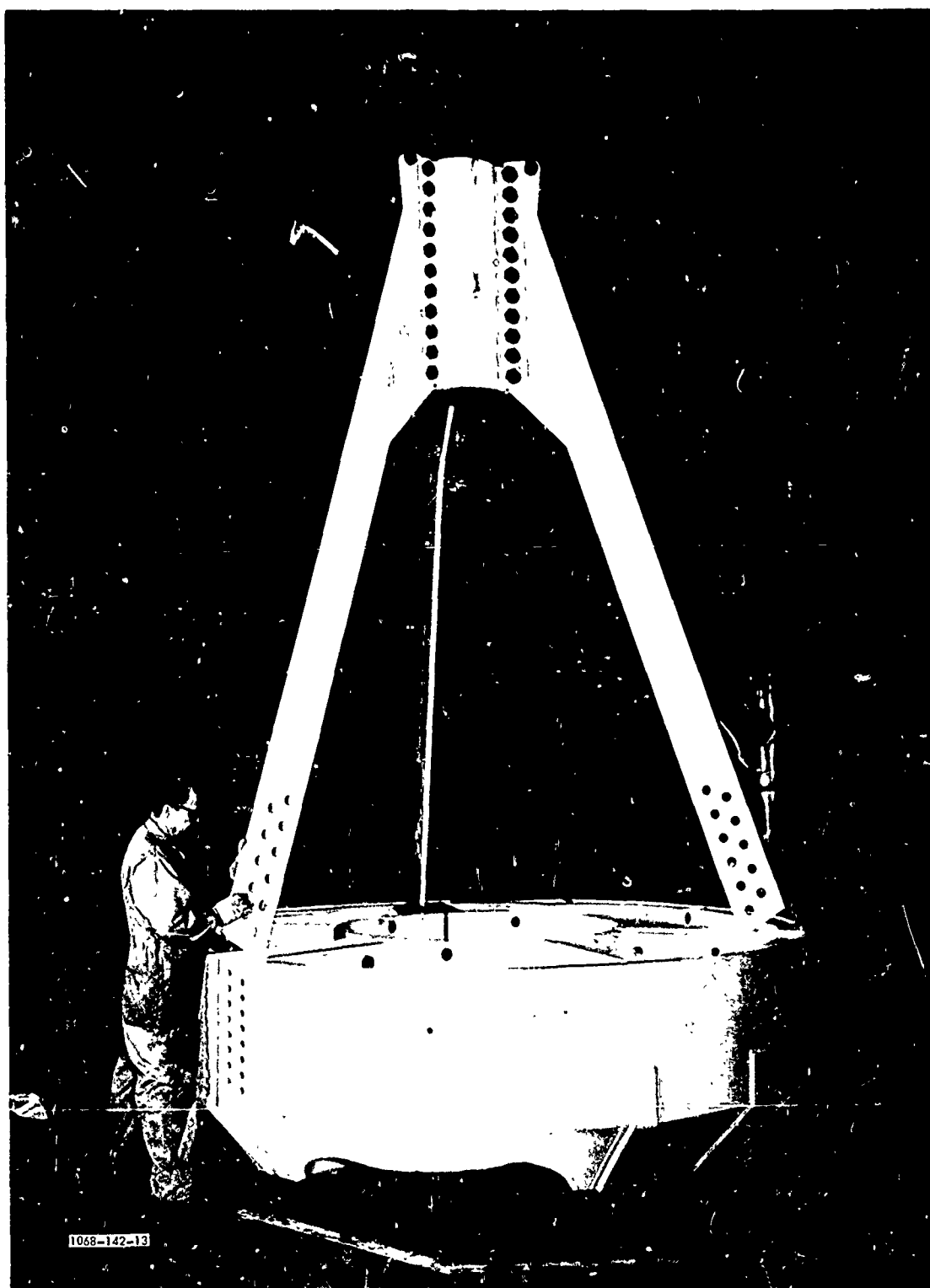
Figure 3-8.   Reaction Vessel Assembly Operation.

Figure 3-9. Assembly of Projectile Rib Sections.

Figure 3-10. Welding of Anchor Assembly.

3.5   SAND AND MUD FLUKE DESIGN

The sand and mud flukes were fabricated in accordance with Aerojet Drawings 1215157 and 1215155, respectively. Both fluke concepts are of similar rolled plate, all-welded, triple alloy steel design. The expanded sand flukes attached to the projectiles are shown in Figure 3-11. A similar view of the expanded mud flukes is shown in Figure 3-12. The sand and mud flukes are completely interchangeable; the supporting bracers are not. The design structural load allowable for both the sand and mud flukes is 100,000 lb. The sand flukes have a triple fluke bearing area of 24.60 sq ft, for a shear perimeter of 37.8 ft. The triple fluke bearing area for the mud fluke is 71.47 sq ft, for a corresponding shear perimeter of 63.0 ft. The folded sand and mud fluke projectiles are shown in Figures 3-13 and 3-14.

3.6   CORAL PROJECTILE

Limited experimental development was required for the coral projectile design because little open literature was available concerning the coral medium in terms of usefulness to anchor design. Two types of coral projectiles were considered. The original coral penetrator is shown in Figure 3-15. The modified projectile (and the more successful of the two designs) was fabricated in accordance with Drawing 1215503. Figure 3-16 is a photograph of the modified projectile, which is an all-welded three-rib configuration fabricated of triple alloy steel. Each rib has 24 serrations, each 2-in. deep by 6-in. long. The serrations are to increase the frictional resistance strength in a vertical pullout mode. For the horizontal loading mode, resistance for maximum holding is provided by the projected rib bearing area. Provisions are made at the top of the projectile for the attachment of two 1-1/2-in. cable, open-jaw sockets with 2-3/4-in. pins. As in the case of the sand and mud projectiles, holding loads are applied through a 1-1/2 x 6 x 37 in. equalizing bridle.

Figure 3-11. Anchor Projectile After Recovery -- Flukes Extended.
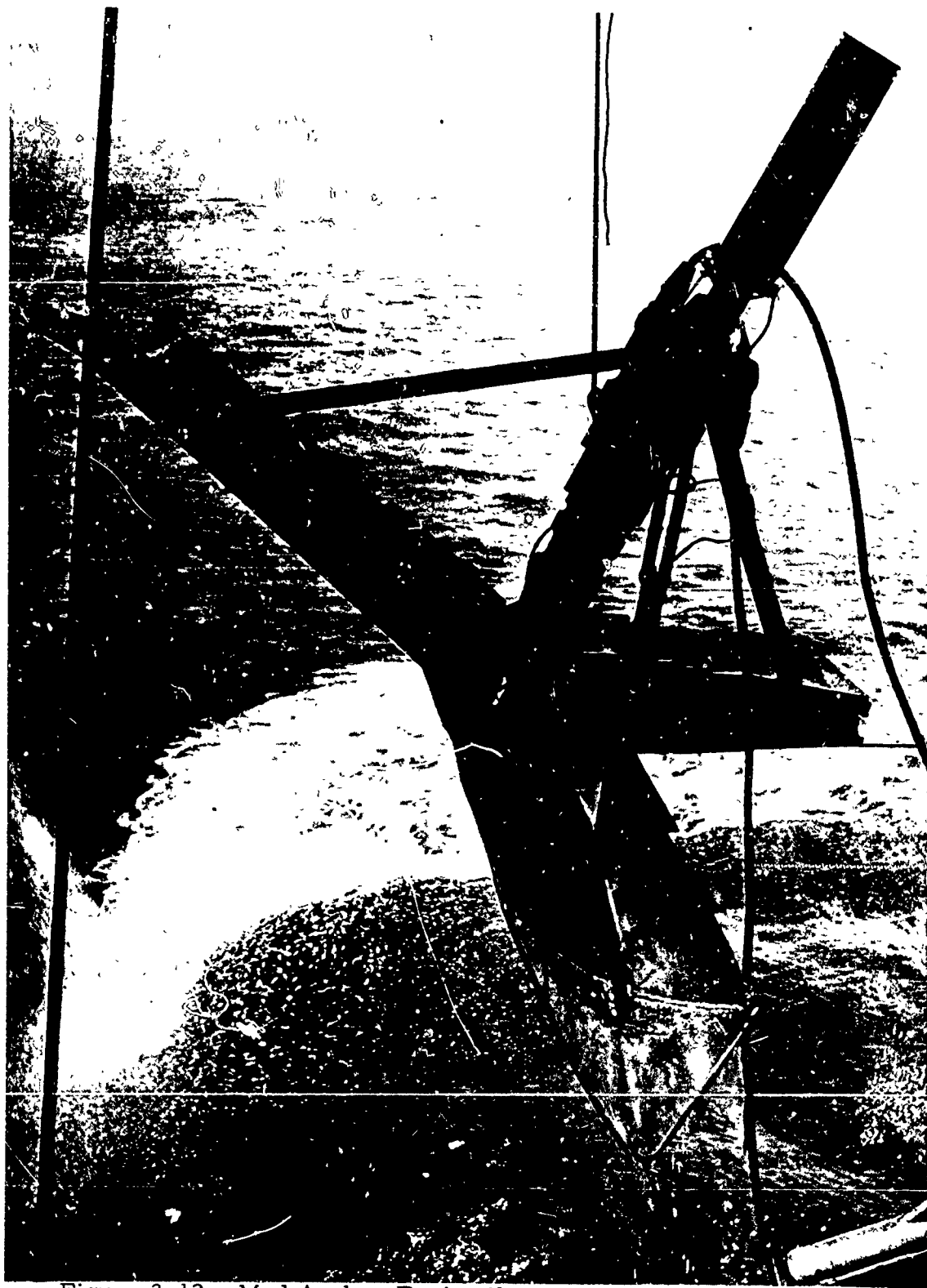
Figure 3-12.   Mud Anchor Projectile -- Flukes Extended.
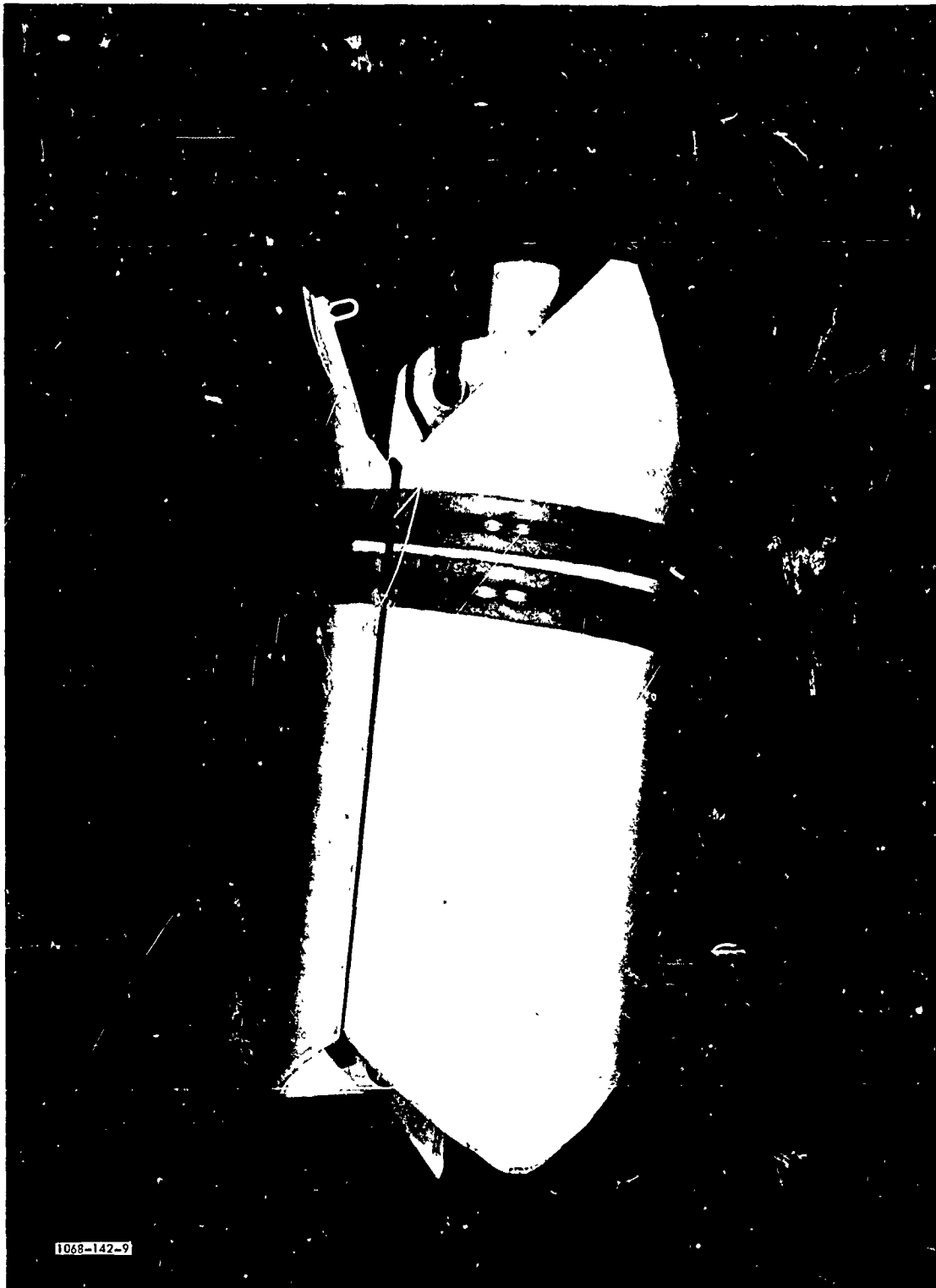
Figure 3-13.   Folded Sand Fluke Projectile.

Figure 3-14. Folded Mud Fluke Projectile.
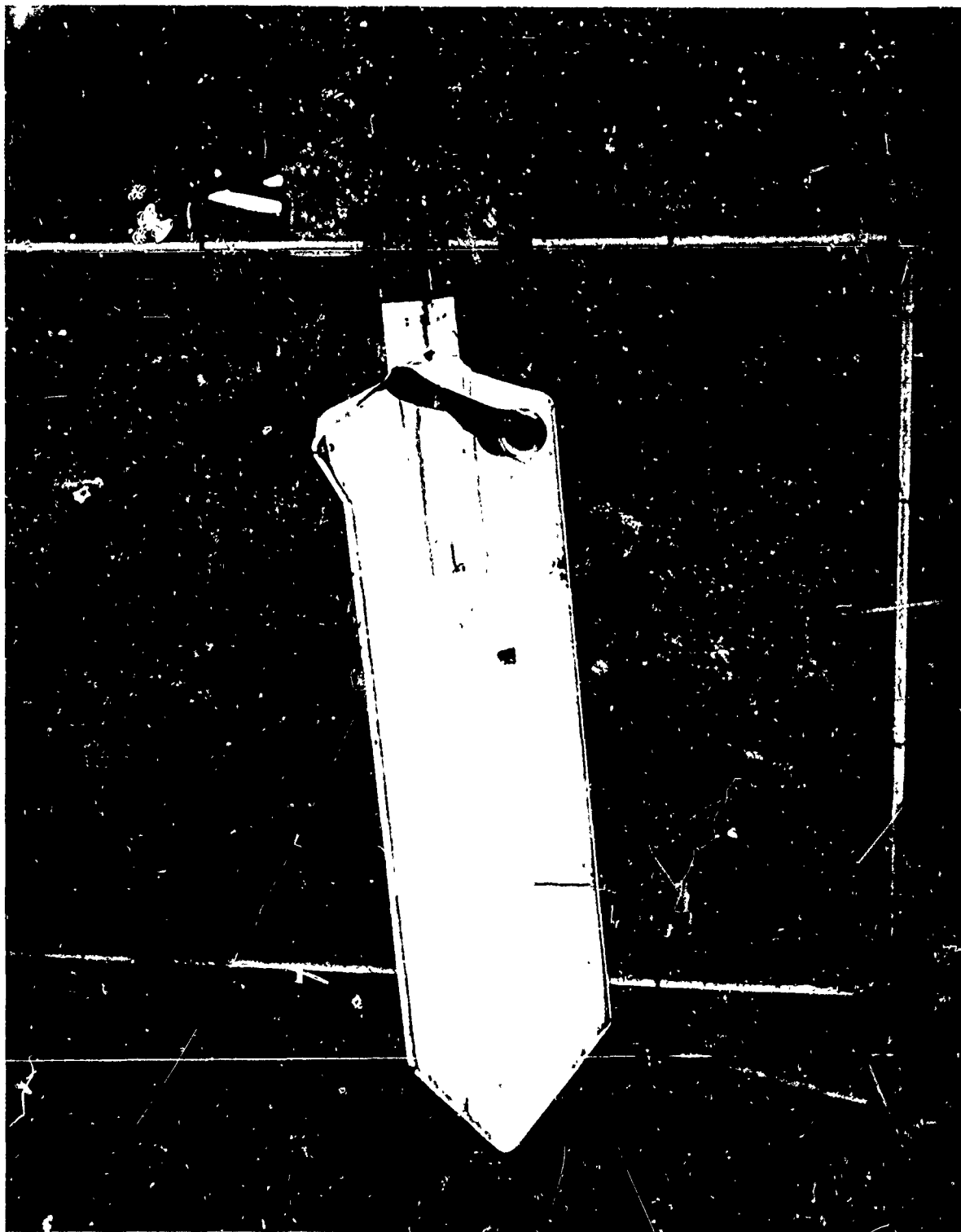
Figure 3-15. Original Coral Projectile Design.
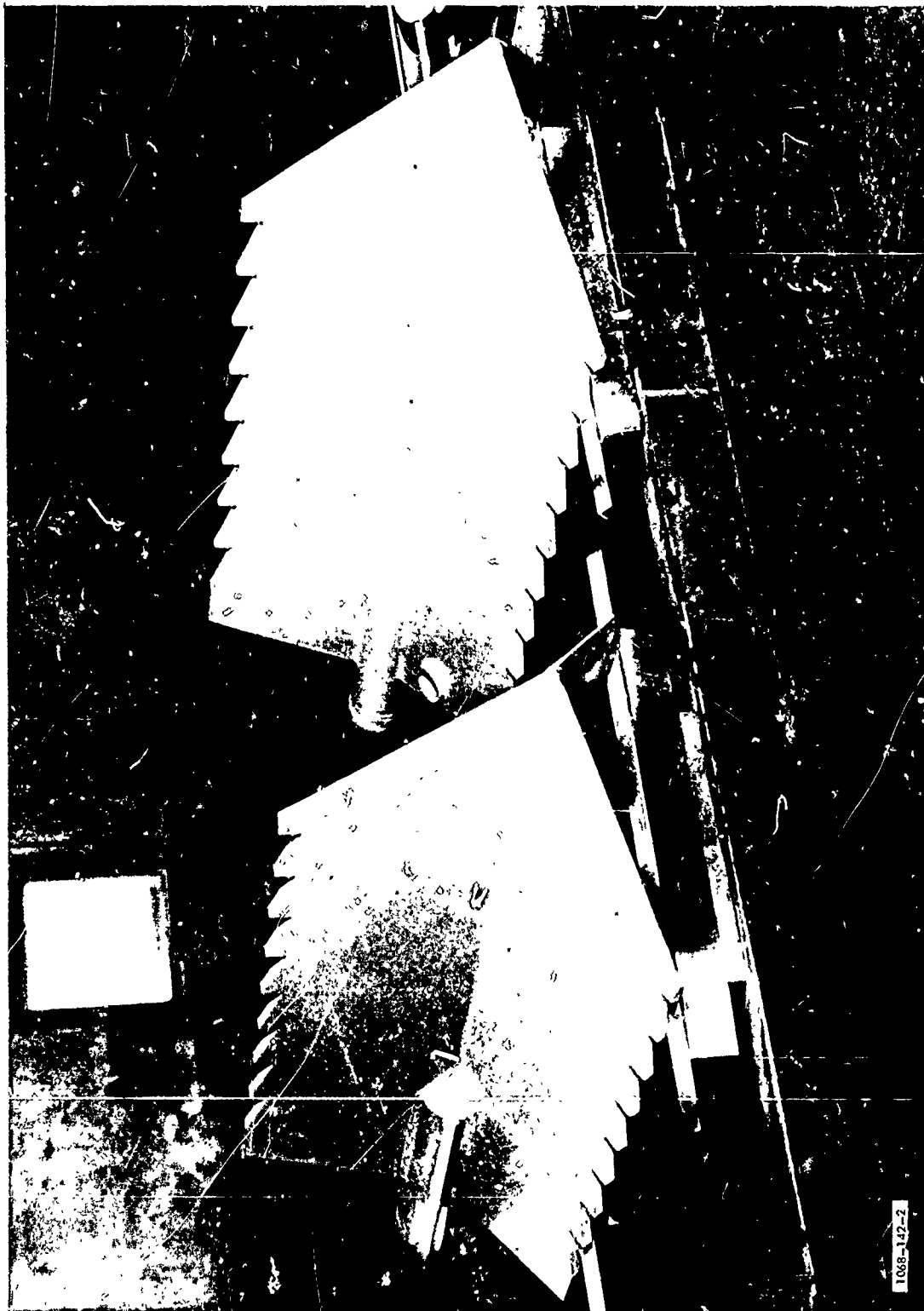
Figure 3-16. Modified Projectile. (Sheet 1 of 2)
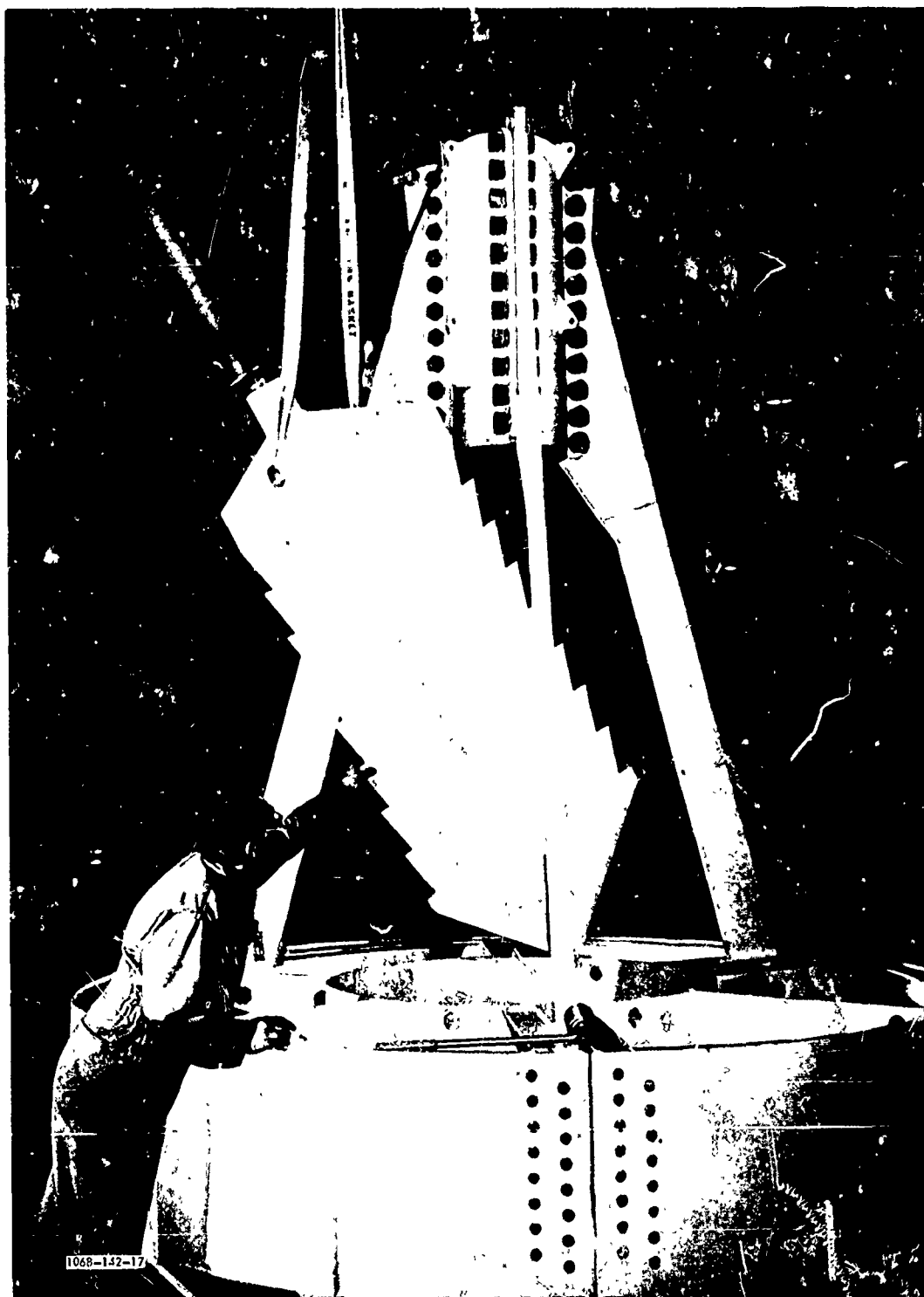
Figure 3-16. Modified Projectile. (Sheet 2 of 2)

Section 4

FIRING MECHANISM

4.1 DESIGN OBJECTIVES

The main design objective of the firing mechanism was that, upon command of the operator on the salvage vessel, it was to be capable of activating the embedment anchor propelling device when it was near, in contact with, or fully supported by the bottom. For safety, a safe/arm device containing a hydrostatically operated in-line/out-of-line slide containing electrically initiated detonators (squibs) was proposed (Figure 4-1). A further safety feature included a spring-loaded, solenoid-actuated ball lock which would hold the in-line/out-of-line slide in the safe position when in the passive (nonenergized) condition. To ensure deck safety, a mechanical safety pull pin that keeps the triggering device in the safe position under any conditions was provided.

To ensure that the anchor was positioned on the bottom at an acceptable angle before firing, a passive indicator was included. This indicator consisted of an inclinometer switch capable of relaying a signal to the control panel indicating whether the anchor was resting horizontally at an angle of 30° or less. An angle greater than this was considered detrimental to the firing and penetration characteristics of the anchor.

It was desired that the mechanism arm at approximately 20 ft below sea level and that arming be completed at 40 ft. If, for some reason, the anchor was retrieved without being fired, the triggering device returned and locked in the safe position.

Other design objectives were:

a.   Two electrical detonators for reliability.

b.   Provisions for an indicator on the firing panel to show whether the firing mechanism was armed or safe.

c.   Provisions for an indicator on the firing panel to show that the electrical detonators have fired. (Indicator lights or firing circuit meters will be used.)

59
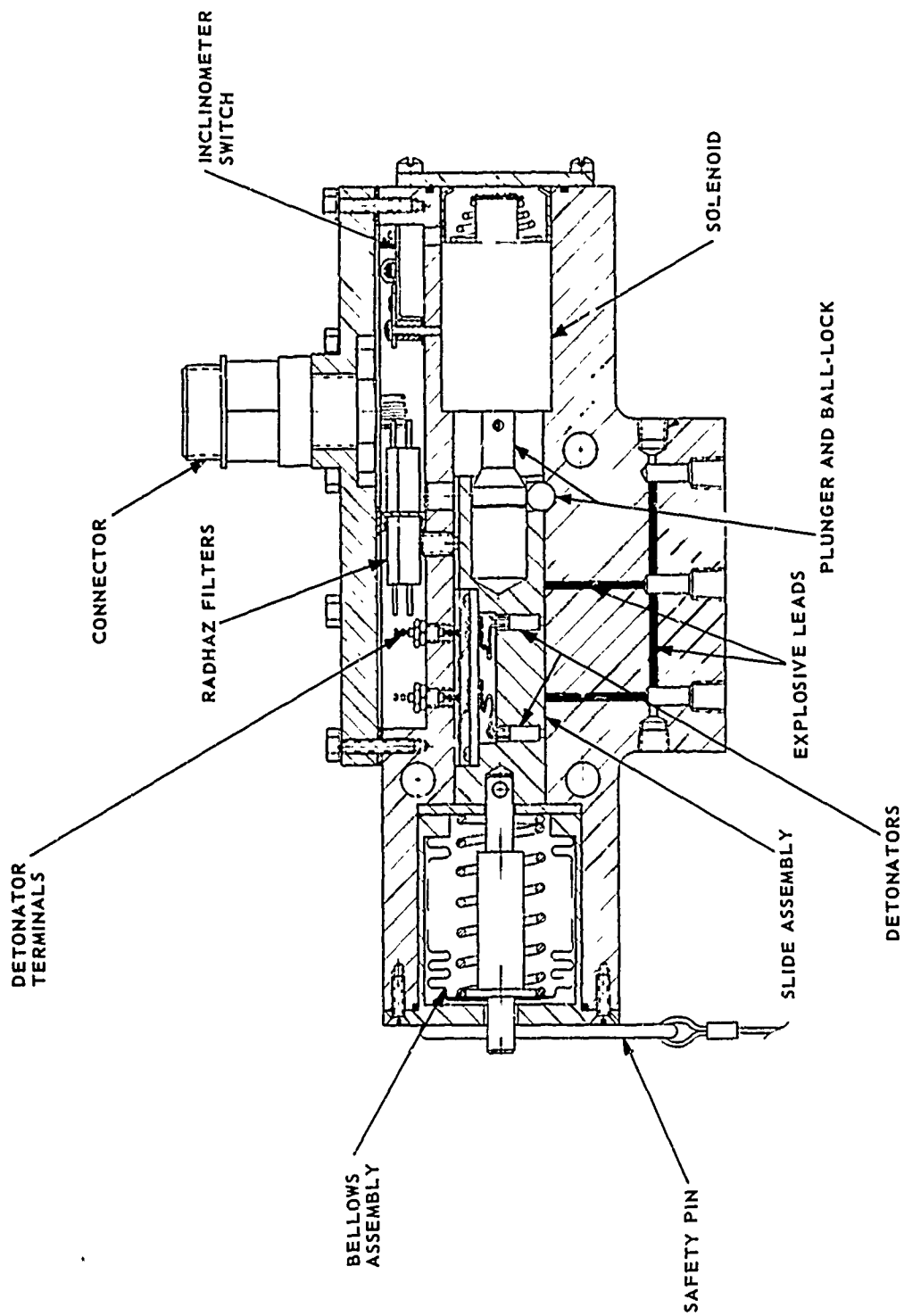
Figure 4-1. Safe/Arm Device.

60

d. Two explosive bolts to separate the down-haul cable plate shackles from the reaction vessel simultaneously with the command to fire.

e. Safety from extraneous electromagnetic radiation (RF energy) in compliance with Specification MIL-P-24014.

f. An embedment anchor with firing mechanisms capable of operating at 50 to 500 ft below sea level.

The foregoing design objectives led to the ordnance system schematically illustrated in Figure 4-2. Figure 4-3 is a photograph of an assembled safe/arm device.

The initiation of the two electrical detonators is the beginning link in the explosive train. Propagation from this point is through secondary explosives that are relatively insensitive to heat and shock. Downstream from the detonators there are no electrical squibs or sensitive primary explosives

The manifold section of the safe/arm contains MDF as explosive links or leads from the detonators to the boosters at the external leads (see Figure 4-1). The detonation is carried from the safe/arm device through the explosive leads to the propellant package and the explosive bolts. For reliability, it was desirable to run two explosive leads from the safe/arm device to the propulsion system charge and one lead to the explosive bolts.

The purpose of the propulsion system charge is to provide the necessary gas pressure, through a high rate of released chemical energy, to drive the anchor projectile into the sea floor. The explosive bolts provide quick release of the plate shackles that hold the down-haul cables to the reaction vessel hull.

The following summarizes the safety objectives of the firing mechanism:

a. Mechanical safety of the triggering system before launch (lanyard-operated safety pin).

b. Incorporation of visual safe/arm indication.

c. Shielding of system from extraneous electromagnetic radiation.

61
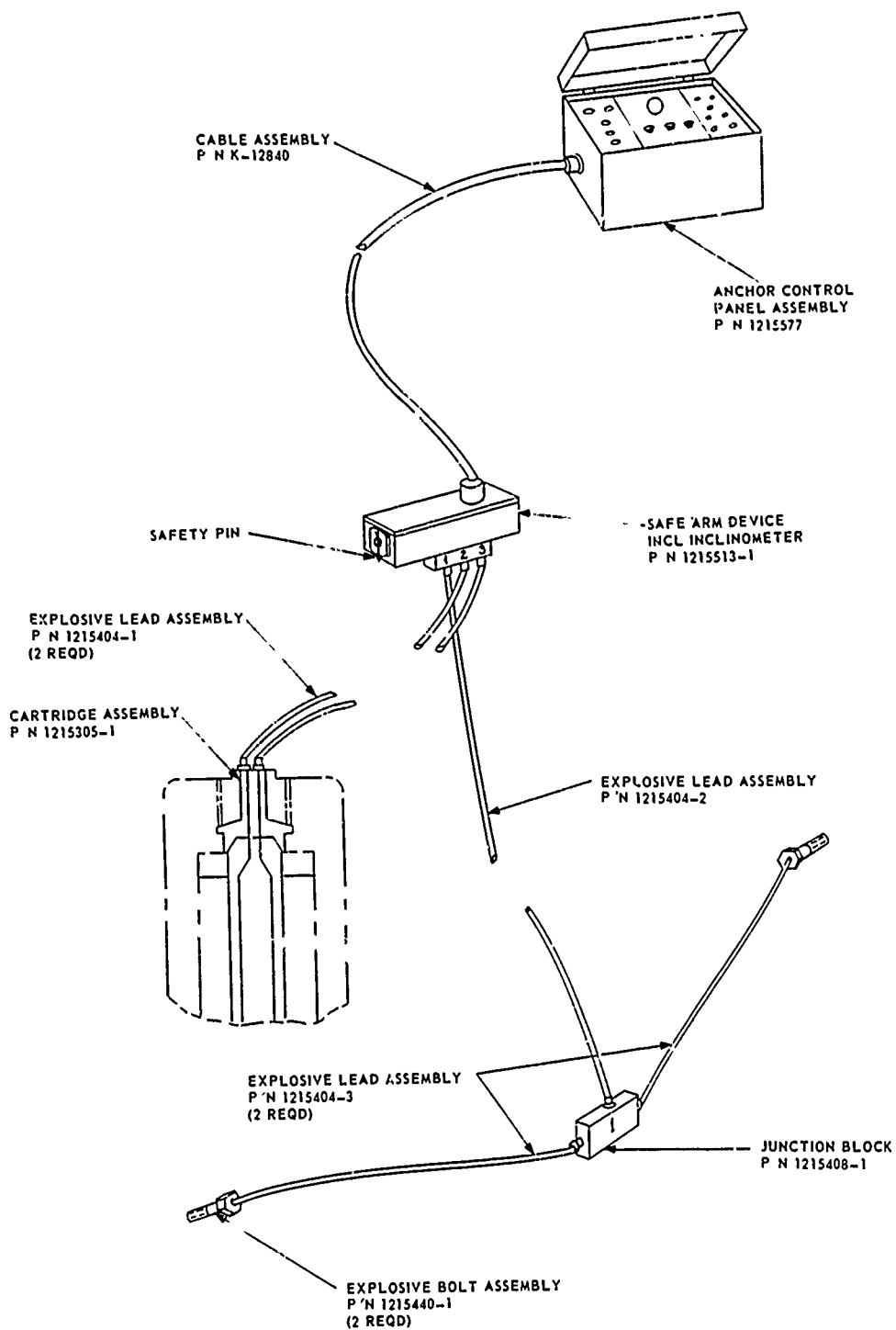
Figure 4-2. Ordnance System.
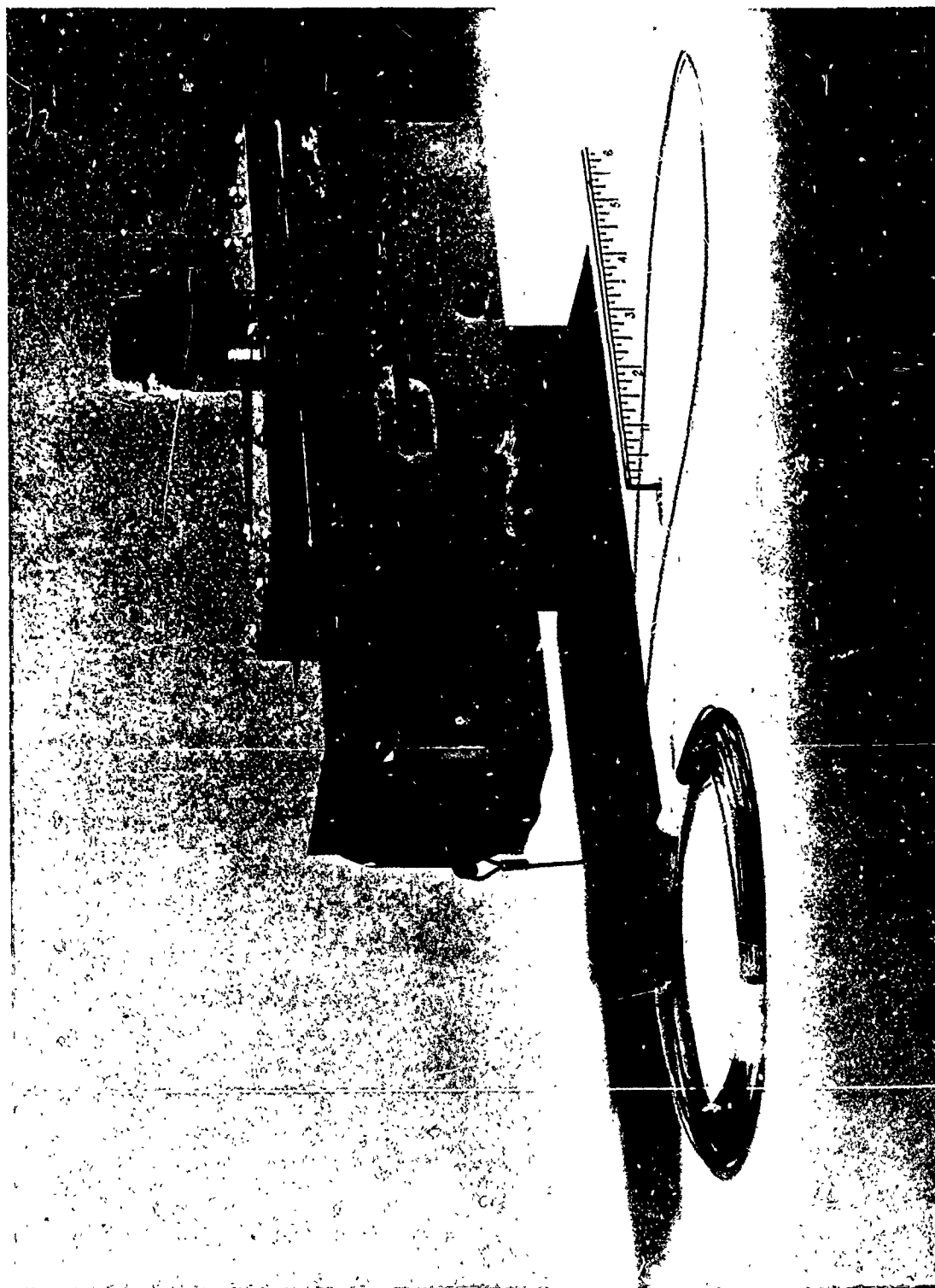
Figure 4-3. Assembled Safe/Arm Device.

d.　Interrupted explosive train.

e.　Positive lock or interrupter in safe position, which upon surface command (actuation of solenoid), will allow device to arm.

f.　At least two arming mechanisms, each requiring an independent source of arming energy (electrical commit-to-arm on surface command and automatic pressure arm).

g.　One arming mechanism, deriving its motivating energy after launch and when the anchor system is safely clear of the ship (hydrostatic pressure at predetermined depth).

4.2　DESIGN AND TESTING

The entire ordnance system was considered in the design principles and practices used to control the hazards of electromagnetic radiation to ordnance, commonly referred to as HERO design or RADHAZ prevention. Preliminary investigations were made to design a completely RF-shielded system from the firing panel through the firing cable and into the safe/arm device. This approach required a firing panel with shielded or filtered input and output leads as well as shielded meterfaces, lights, and switches. The cable assembly also required an RF shield surrounding all the conductors, and the mating connectors at the firing panel and at the safe/arm device had to be of the shielded type. All joints required RF-type gaskets. It became evident that an entirely shielded system would seriously affect the design flexibility and result in a cumbersome and unwieldy system, especially as far as the cable assembly was concerned.

In a coordination meeting with the HERO design group at the Navy Weapons Laboratory, Dahlgren, Virginia, it was determined that RF filters placed within the safe/arm device just in front of the terminals to the detonators would be the most desirable way to achieve the HERO design objective. It would also eliminate all RF shielding required upstream of the safe/arm device. The HERO design group further recommended using the RADHAZ-type filter assemblies used by U. S. Naval Air Development Center at Johnsville, Pennsylvania. These filters are manufactured by Sprague Electric Company and effectively filter out electromagnetic radiation (Figure 4-1). In order to prevent RF signals from entering the cavity housing

the detonator terminals, an RF-type gasket was recommended for installation between the housing and the top cover, with the gasket extending over the bulkhead into which the RF filters are installed.

Aside from the RF principles involved, the design objectives and the design of the safe/arm device utilized many design features previously used on safe/arm units employed on missile systems. The design of the safe/arm device for the embedment anchor, however, required a slightly different approach to withstand the specified water pressure and to remain waterproof under all conditions. Under the circumstances, the size and weight of the unit was considered to be of lesser importance, and, consequently, miniaturization of the various components was not attempted.

The selection of the Type D3A2 detonators used in the safe/arm units was based on previous experience. The Type D3A2 detonators (produced by the Hercules Powder Company and shown in Figure 4-4) had proved their superior reliability and performance in several safe/arm devices designed and produced by Aerojet for the Minuteman missile.

A prototype unit of the design shown in an exploded view in Figure 4-5 was derived from preliminary design layouts. Because prototype test units were required early in the program, procurement of component parts began when preliminary subtests were conducted.

Tests were conducted to determine the forces required to move the in-line/out-of-line slide assembly and the breakaway forces required on the solenoid plunger (Figure 4-6). From these preliminary tests, the sizing of the bellows assembly and the solenoid was determined.

Test blocks (simulated manifolds) were fabricated and tests were conducted on the interfaces from detonators to the MDF leads and, in turn, to the boosters on the explosive leads (Figure 4-7). The results were that the 5 gr/ft MDF with PETN explosive core and PETN-loaded boosters on the explosive lead assemblies resulted in a reliable explosive train. Prototype assemblies were then procured and assembled for use in simulated system checkout as described in Appendix B.

The design of the inclinometer switch followed several approaches, with one design using a silver-plated ball housed in a silver-plated, domed dish (Figure 4-8). Experiments with a mercury bead in a similar shaped housing were conducted; however, these preliminary concepts were later abandoned in favor of the design illustrated in Figures 4-9 and 4-10. This simple

Product Data
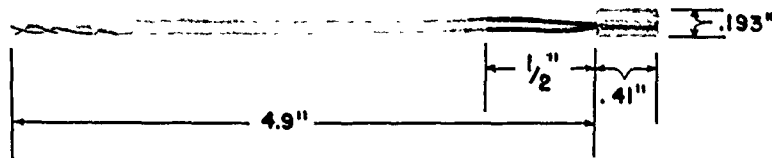
WIRE LEADS: #25 AWG copper, solid
   INSULATED SECTION: Extends 1/2-in. above plug, enamel insulation
   BARE SECTION: 3-3/4-in. tinned, 1-in. twist shunted
CASE: Stainless steel
SEAL: Phenolic
BRIDGE RESISTANCE: 0.04-0.10 ohm; wire type
IGNITION: Lead styphnate /lead azide type
DELAY TIME: -
MAIN CHARGE: (Detonating) lead azide/PETN (165 mg.)

TYPICAL PERFORMANCE DATA

These data should not be used for specification. They are based on information developed in design tests, background comparisons, and moderate production runs. Values listed are average, and exact limits cannot be guaranteed. Applications that require high reliability or performance under severe environmental conditions, or where the use is new, may require special modification or testing.

FIRING CURRENT   - Test current (suggested max.)   10 ma.
(see   MNFC   - Max. nonfire (safety design, destructive)   1.0 amp., one 30-sec. pulse
Section   MFC   - Min. fire (borderline, not recommended)   4.0 amp.
4.6)   RFC   - Recommended (all-fire)   5.0 amp.

FIRING TIME   - Amp. (d.c.)   4.0   4.5   5.0   5.5
(see Section 5.1)   - Time (milliseconds)   0.57   0.42   0.23   0.2

HIGH TEMPERATURE   - Functioned normally (Time: 4 hr.   16 hr.   1 yr.   3 yr.
                  after storage at: (Temp. °F.: +200   +165   +120   +70

LOW TEMPERATURE   - Functioned normally at: -65°F.
(see Section 5.4)

HIGH ALTITUDE   - Functioned normally at 150,000 ft.
(see Section 6.1)

MOISTURE RESISTANCE - Withstood JAN-C-25 and MIL-STD-304 temperature and humidity tests

RELIABILITY   - 99.9+%
(see Section 7.2)

OUTPUT   - Steel dent plate test, will produce a min. of 0.011-in. indentation when
(see Section 6.4)   confined in a plastic sleeve (NAVORD OS-8166)

TYPICAL USES: Compact, high-current, moderately high-temperature detonator

REFERENCES: DETONATOR, D3A2

SHEET: HD-414

Sections referred to are in
HERCULES HANDBOOK OF INITIATORS AND ACTUATORS   DATE: 3/21/60
                                                2BC114

EXPLOSIVES DEPARTMENT   *HERCULES POWDER COMPANY*
                            WILMINGTON, DELAWARE

Figure 4-4.   Hercules Powder Company Type D3A2 Detonator
Product Data.
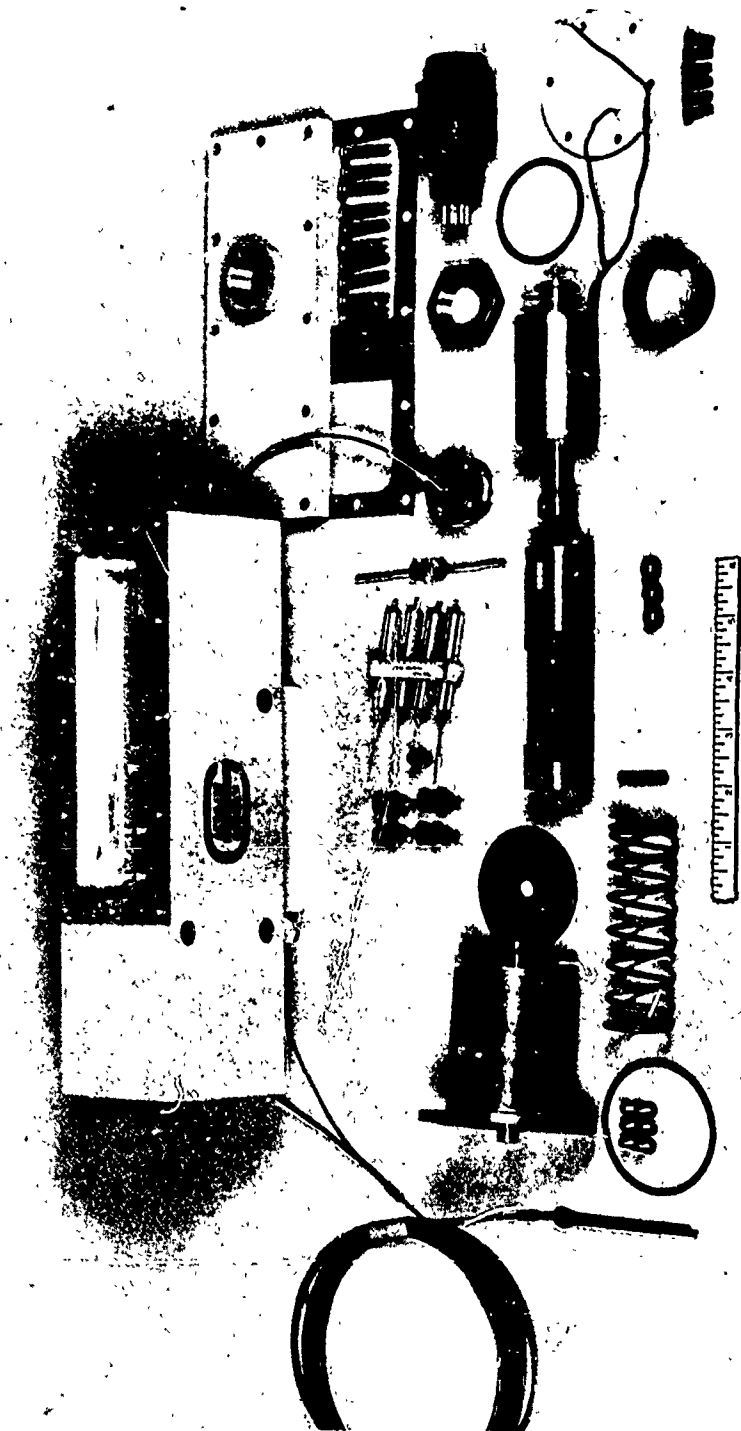
Figure 4-5. Prototype Unit, Exploded View.

268-68-3

NOTE: EQUIPMENT SETUP ALLOWED ONLY 350-LB FORCE ON SLIDE

S/A DEVICE
TEST ON BREAKAWAY FORCE
ON SOLENOID PLUNGER
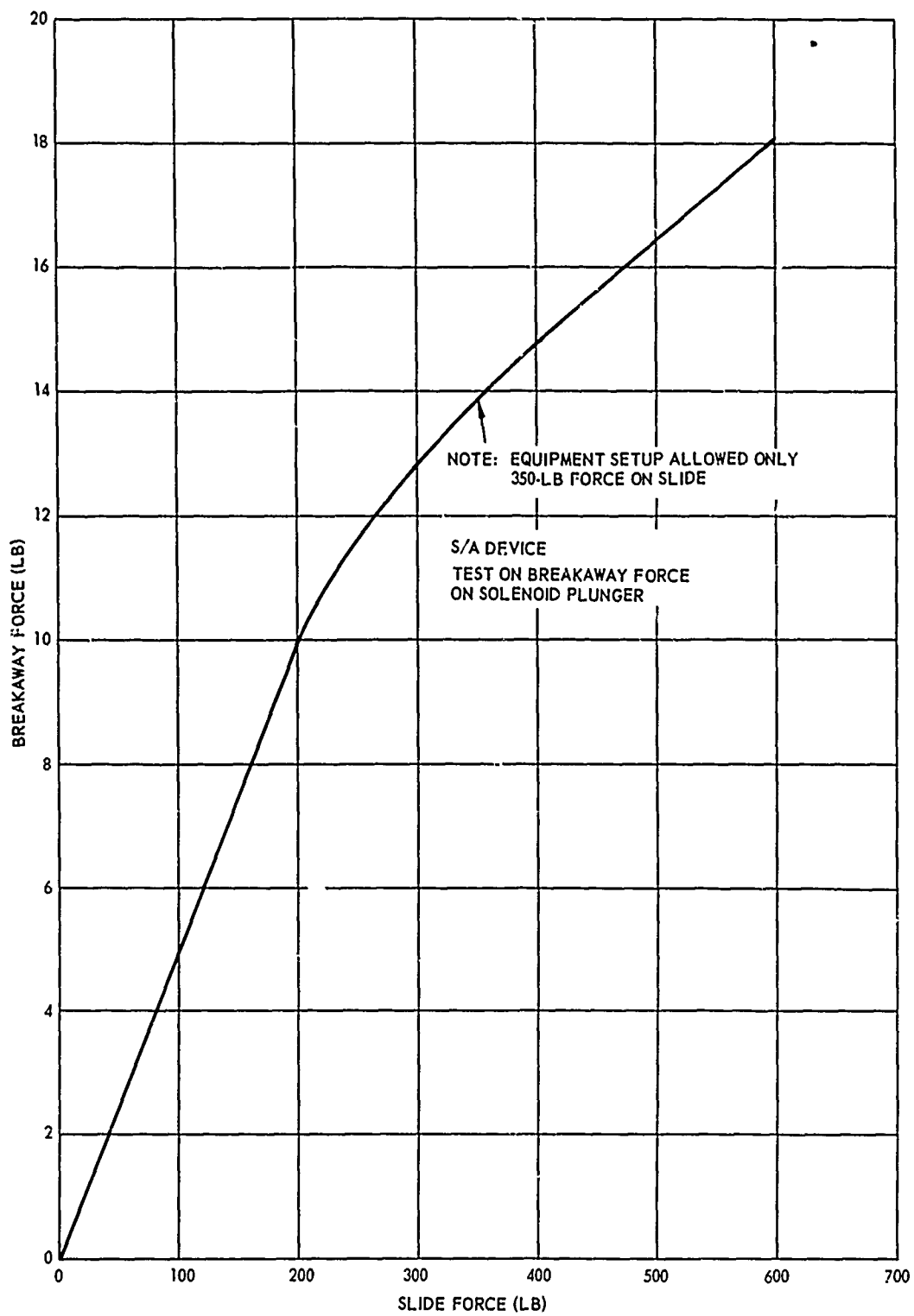
Figure 4-6.   Breakaway Force as a Function of Slide Force.

DETONATOR, HERCULES D3A2

TEST BLOCK II

2.85 (REF)

0.090-IN. GAP

0.75 REF

5 GR MDF, LEAD COVERED, ~1.32 IN. 1 REQ'D

5 GR MDF, LEAD COVERED, ~1.28 IN. 1 REQ'D

2.55 REF

PLUG, ST'D PIPE, ST'L 1/8-IN. SIZE, 2 REQ'D

1214276-1 BOOSTER 105 MG (1.6 GR) PETN (REF)

TEST BLOCK I

1214228-1 SCREW (REF)

1214286, CONNECTOR SUBASSY, EXPLOSIVE 6-IN.-LONG PIGTAIL SIMUL 2 EA

1214285, CORD CONFINED 2.5 GR/FT (REF)

1.50 REF
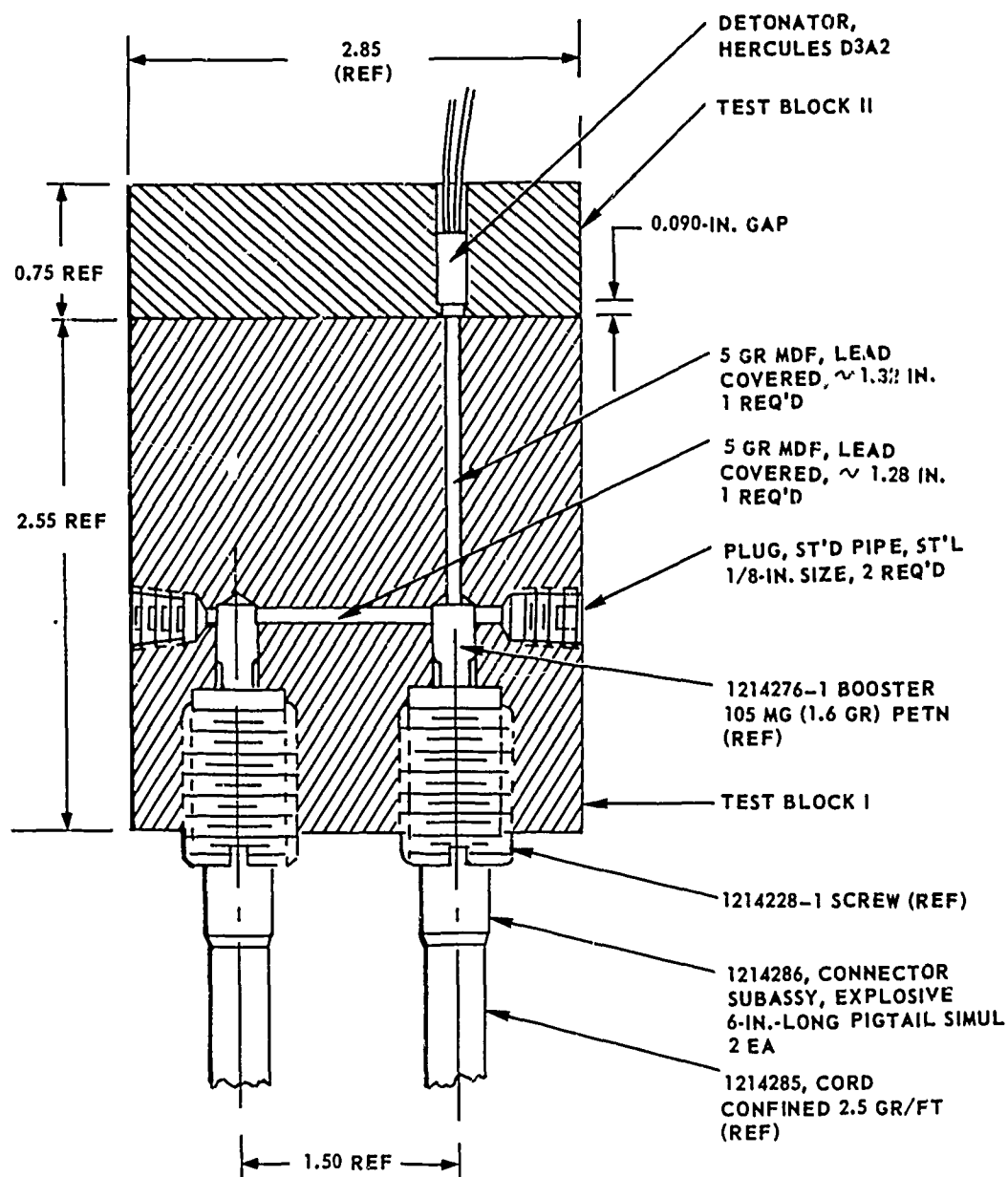
TEST BLOCK THICKNESS = 1.00 IN.
MATERIAL: 6061-T6 ALUMINUM
TOTAL EXPLOSIVES: APPROX 9.0 GR (0.45 GM)

Figure 4-7. Test Configuration of Safe/Arm Device.

69
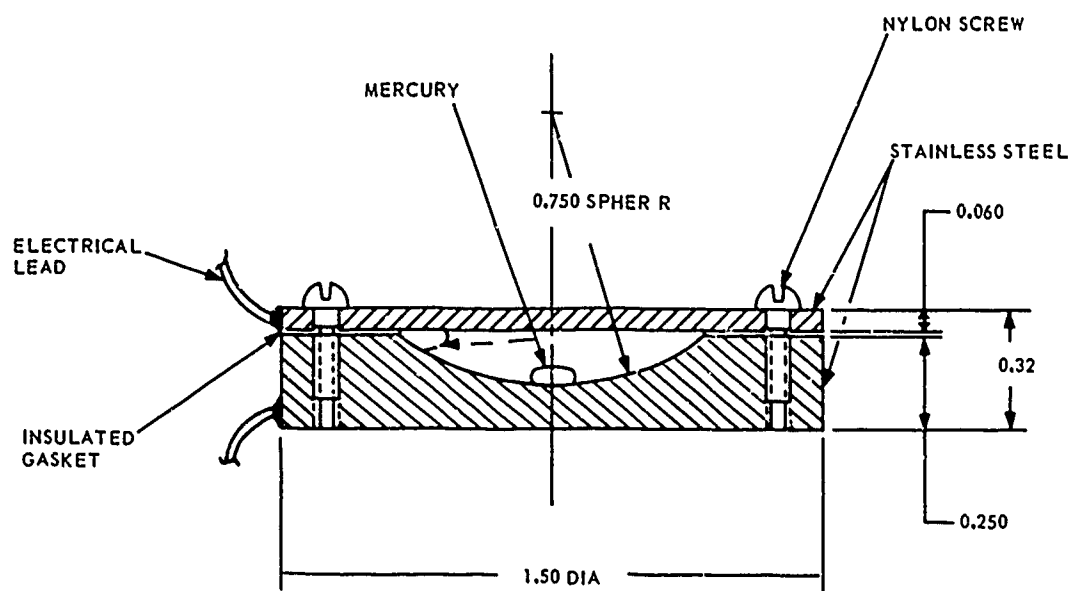
SECTION THROUGH INCLINOMETER
SWITCH WITH FLAT TOP PLATE
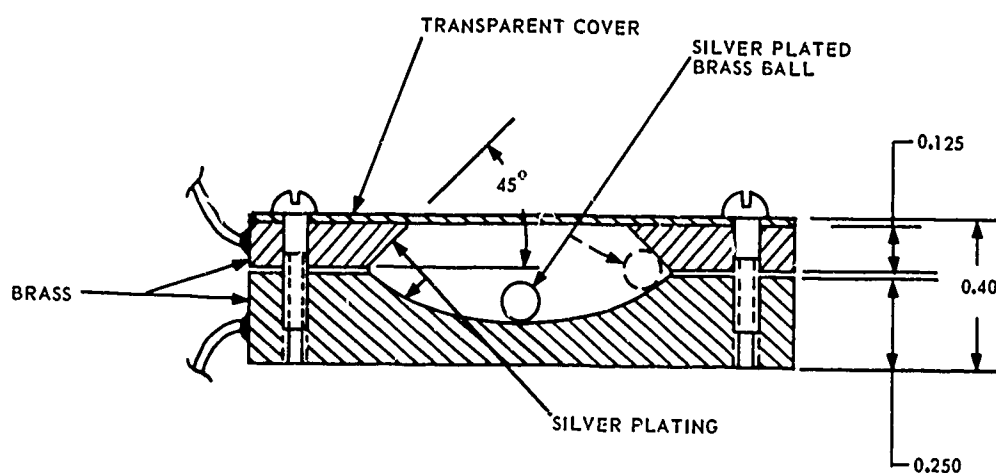
SECTION THROUGH INCLINOMETER
SWITCH WITH 45° TOP PLATE

NOTE: ALL DIMENSIONS ARE IN INCHES.

Figure 4-8.   Prototype Inclinometer Switch Assembly.

NOTES:

1. INTERPRET DRAWING PER MIL-D-1000.

2. BOND ITEM 4 TO ITEM 3 AS SHOWN USING A-12 ADHESIVE. ITEM 4 MUST BE PERPENDICULAR TO ITEM 3 WITHIN ±2°. ORIENTATION OPTIONAL. ITEMS 3 AND 4 MUST NOT CONTACT EACH OTHER.

3. APPLY KETONE OR EQUIVALENT ON TCP SURFACE OF ITEM 2 PRIOR TO SEALING ITEMS 2 AND 3.

4. ASSEMBLE IN INERT ATMOSPHERE.

5. SWITCH TO MAKE CONTACT AT 30° - 2° TO HORIZONTAL PLANE.

6. MARK PER AS D 5215 N WITH PART NUMBER 1215734-1.
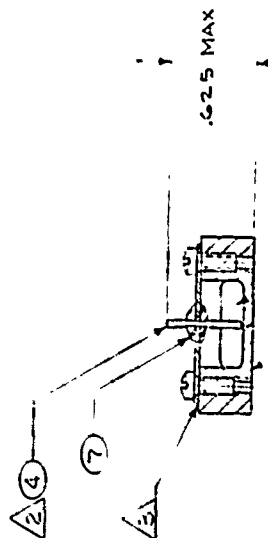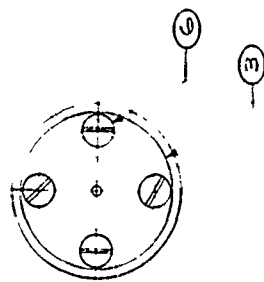
QTY REQD	SYM	CODE IDENT	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	UNIT WT.	ZONE	ITEM NO.
A R		98911	A-12	ADHESIVE	ARMSTRONG PRODCO INC WARSAW, INC	COML GRADE			7
4				SCREW, FIL HD	4-40-UC-2AX .37LG-CRCS	COML GRADE			6
22 G					MERCURY METAL	TECH GRADE			5
1			1215760-1	PIN, CONTACT					4
1			1215733-1	PLATE, TOP					3
1			1215732-1	BASE					2
			-1	ASSY					1
				LIST OF MATERIALS					

Figure 4-9. Inclinometer Switch Design.

71
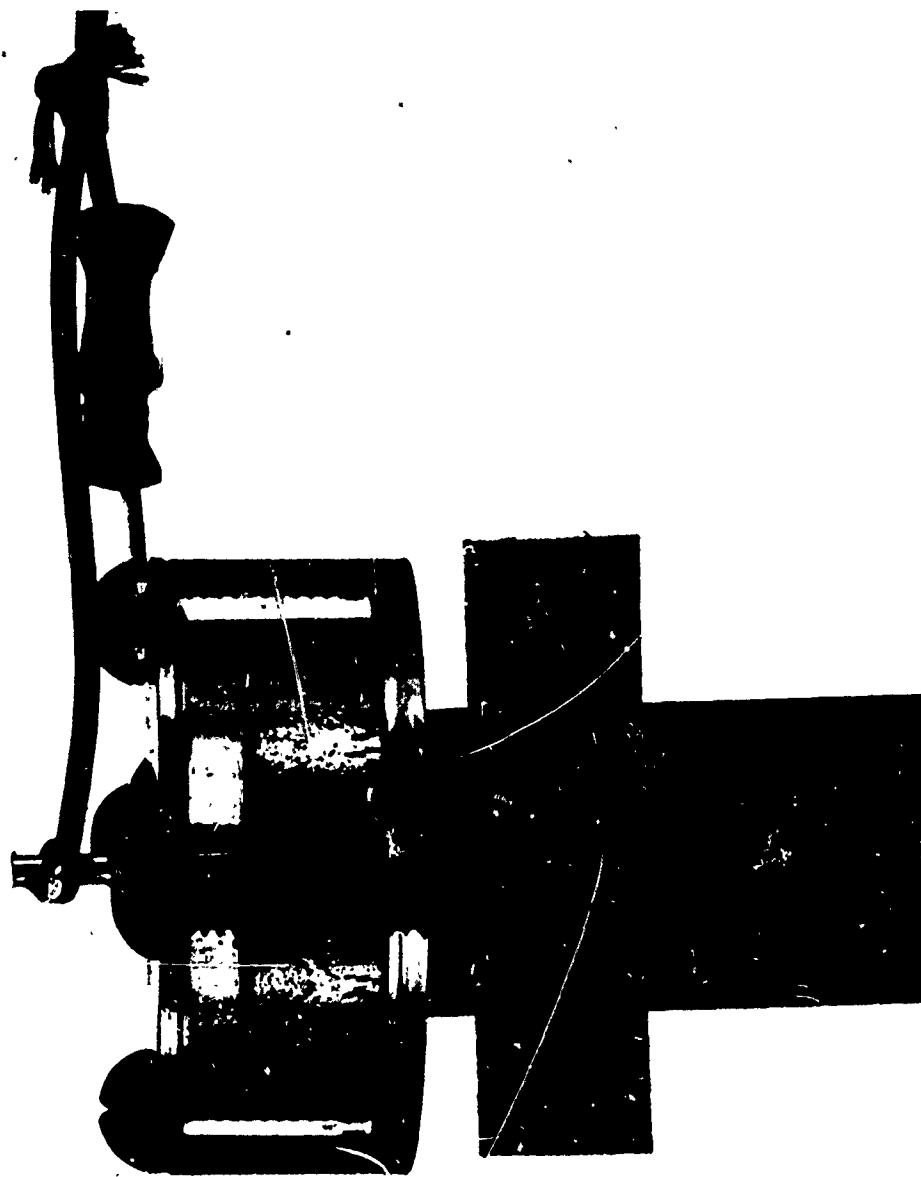
Figure 4-10. Inclinometer Switch.

268-68-4

72

switch assembly proved to be completely reliable. It has a center electrode insulated from the top plate, which also serves as the other electrode. The housing is made of acrylic plastic. The switch is normally in the open position, with closing occurring when the switch is tilted so that the mercury level contacts the top plate. This function occurs at 30° to the horizontal and because of the inherent design holds true for the 360° plane.

Some design problems were experienced with the RF gasket used at the top cover. An RF shielding type of material referred to as "Polastrip" (manufactured by METEX Corporation, Edison, New Jersey) was selected for the gasket. This material consisted of an oriented-wire-mesh screen embedded in a matrix of elastomeric material to produce a combination pressure and RF shield. The embedded mesh contained a large number of wires aligned perpendicular to the surfaces to be shielded.

The gaskets for the first prototype models were made from 0.062-in.-thick Polastrip or Polasheet having a durometer hardness of 40. In a waterproofness test conducted in accordance with Test Procedure 1325-4 (Appendix B), it was found that the gasket did not exhibit the water-sealing capabilities claimed by the manufacturer. In the 500-ft waterproofness test, the top cavity was completely filled with water. Additional tests were conducted to determine the possibility of effecting a seal by using the selected gasket material and changing the torque on the attaching bolts or by using conductive epoxy at the joints. Simultaneously, a metallic gasket consisting of a soft wire material (lead, copper, or aluminum) was investigated. The details are presented in Appendix C. At this time, the METEX Corporation advised that they had started manufacturing Polasheet with aluminum wires embedded in silicon rubber and having a durometer hardness of 70. This gasket was tested (see Appendix F) and hydrostatic tests proved that it produced the type of seal desired. Consequently, gaskets made from material having a 70 durometer hardness were procured.

In order to determine the in-line/out-of-line safety statistics of the detonator and the MDF explosive leads, Bruceton tests were conducted on the detonator safe/arm distance as outlined in Test Procedure 1325-1 (Appendix D). Evaluation of these results indicated that the 50% reliable (safe) distance between the centerline of the detonator and the centerline of the MDF train was 0.246 in. The standard deviation is approximately 0.030 in. The 99.99% reliable distance usually is three increments (in this case, the increment was 1/32 in.) above the 50% distance. Therefore, the reliable distance in this case is approximately 3/8 in. The in-line/out-of-line distance had originally been set at 1/2 in., and it was decided to leave it at this distance since the extra 1/8 in. gave an added margin of safety, as well as allowing for anticipated tolerance buildups.

Another design factor involving the entire system was the requirement for power to operate the firing panel and the solenoid and to fire the detonators. Since all ships involved in salvage have 115-vac power readily available, it was decided to design the panel for 115 vac, 60 Hz with a rectifier to obtain 28 vdc for the firing circuit and 110 vdc to operate the arming solenoid. To avoid power loss in the 600-ft-long cable assembly, 14 gage conductors were selected, with 7 being the absolute minimum. The end fittings on the cable assembly were waterproof, with a molded and extruded neoprene jacket protecting the bundle of individually insulated conductors. Once the cable requirements were established, the cable assembly (Figure 4-11) was procured. Several tests were conducted in which the detonators were fired from the firing panel through the cable assembly to verify compliance with the design criteria.

The amount of power, switching function, voltage, and power requirements for the solenoid were a matter of tradeoff of the various parameters. To achieve maximum power in the solenoid line at the beginning of the stroke and yet obtain a solenoid with resonable on-time for releasing the ball-lock, it was decided to use 110 vdc. The voltage actually drops to approximately 90 v at the end of the 600-ft-long cable assembly.

After initial tests determined the forces required to move the slide assembly, the configuration and design of the bellows assembly were firmly established. The bellows were made of beryllium-copper and the bellows housing was made of Monel (Figure 4-1).

Tests were conducted to determine the size of spring required to allow the unit to arm at a depth of 40 ft. In these tests, hydrostatic pressure was applied to the bellows assembly by means of a hydraulic water pump, as shown in Figure 4-12. A special adapter was used over the bellows end plate. Using this arrangement, checks could be made on both the ball-lock safety and the solenoid release.

The design of the bellows assembly is such that the manufacturer (Robertshaw) stipulated that the maximum pressure in the extended (safe) position (Figure 4-1) should not exceed 100 psi. Therefore, the anchor assembly, and consequently the safe/arm device, must not be lowered below 225 ft (equal to approximately 100 psi) unless the solenoid release has been actuated. Actually, the solenoid should be actuated when the assembly is between 20 and 40 ft below the surface.

Once the various power requirements and the number of circuits required had been determined, the design of the firing panel became routine. Figure 4-13 is an electrical diagram of the anchor control panel, and Figure 4-14 is a photograph of the firing panel.

Figure 4-11. Cable Assembly.
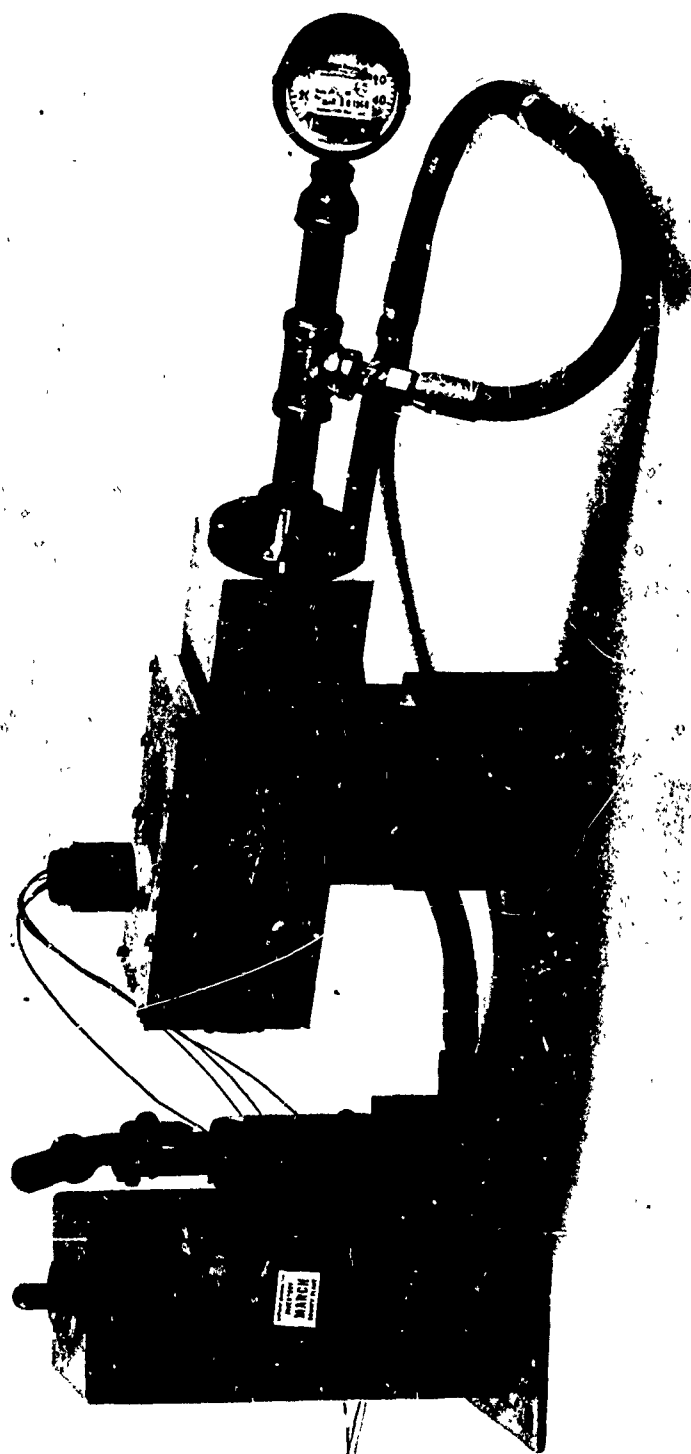
Figure 4-12. Hydraulic Water Pump.

268-68-2

Figure 4-13. Anchor Control Panel Electrical Schematic.
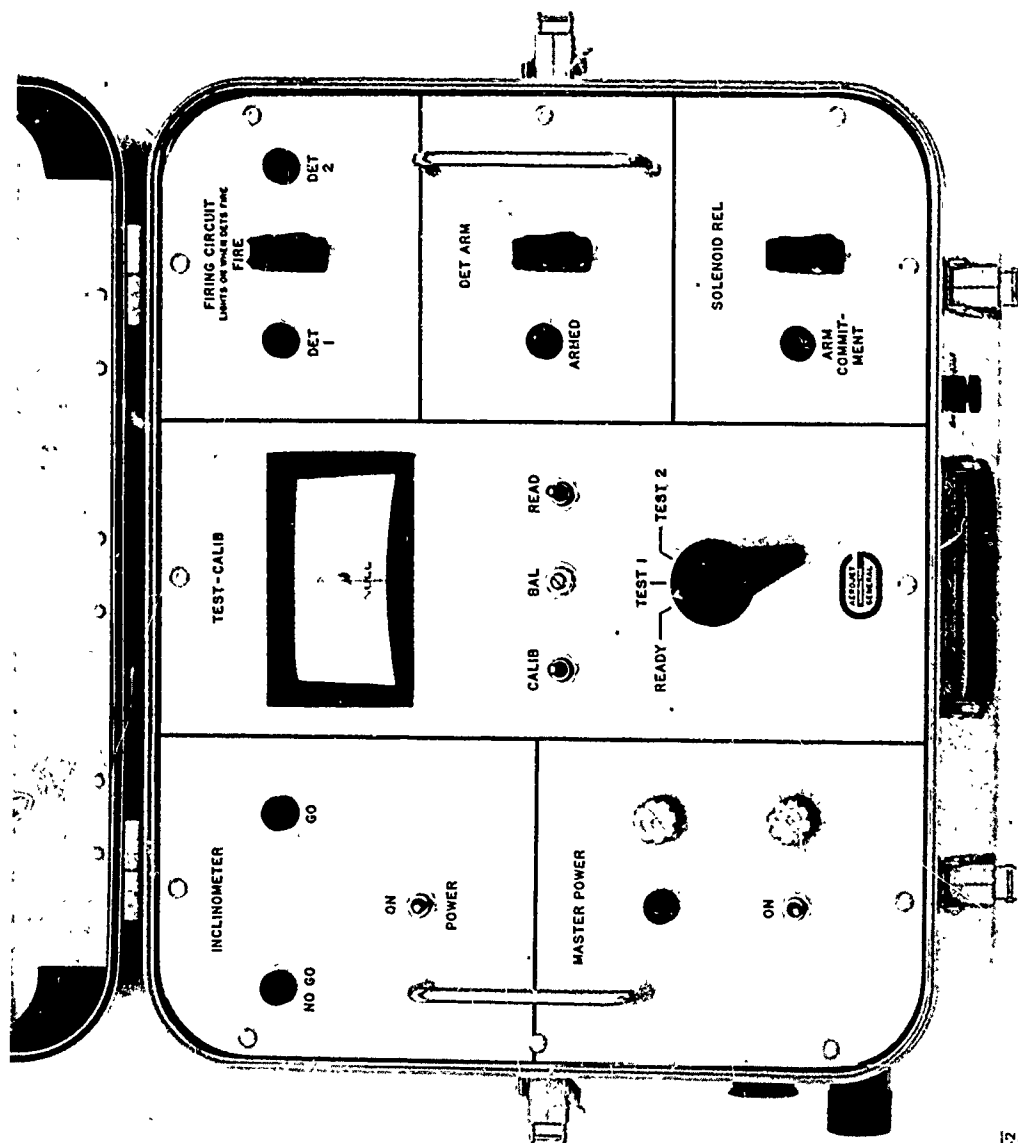
Figure 4-14. Firing Panel.

The design of the explosive leads was relatively simple. Based on previous experience, 10 gr/ft PETN explosive-loaded, lead-jacketed MDF was selected with PETN-explosive-loaded boosters at each end. Instead of using a bonded adapter, sleeve nuts, and O-rings to attach the explosive leads to their respective terminations, the use of slightly modified commercial tube fittings (Swagelok) proved to be successful. (See Figure 4-15.) Both the initial assembly and the final installation of the leads were simplified. For external protection of the MDF against accidental damage, the MDF is encased in plastic tubing. The explosive leads are attached to the structure with standard tubing clamps at regular intervals.

The design of the explosive bolts followed previous design practices. The purpose of the explosive bolts is to separate the two down-haul cable plate shackles from the reaction vessel at time of firing. From a size and strength standpoint a 3/4-in.-diameter bolt was considered suitable. Consequently, a standard AN12-26A bolt was modified to include a charge cavity and a circumferential separation groove, as shown in Figure 4-16. This bolt has a tensile strength of approximately 20,000 lb. To determine the optimum explosive charge required to effectively separate the bolt under water, "load sizing" tests were conducted on prototype bolts in accordance with Test Procedure 1325-2 (Appendix E). Figures 4-17 and 4-18 show the components before and after tests, respectively. The tests were highly successful, with bolt separation occurring even with minimum explosive load. In all the prototype testing, only one explosive bolt failure occurred; it was attributed to an error in installing the explosive lead booster into the explosive bolt cavity at the time of shipboard installation.

Tests conducted on the ordnance components as a system consisted of one functional test at approximately a 50-ft depth, in accordance with Test Procedure 1325-4 (Appendix C). This test was conducted at Hunters Point in San Francisco Bay. The test was an unqualified success, with all ordnance interfaces, explosive leads, and explosive bolts functioning as intended.

A final firing mechanism checkout was made in conjunction with the anchor coral test conducted in Key West, Florida. Here, a complete ordnance system was installed on the anchor assembly, with the safe/arm controlled through the cable assembly from the anchor control panel. The test firing was successful, except that one explosive bolt failed to initiate, as previously noted. Underwater examination indicated that the explosive lead to the bolt interface had propagated properly, and it is assumed that the booster at the end of the explosive lead had not been installed properly. This malfunctioning did not affect the penetration of the coral projectile, and the bolt was manually removed to free the down-haul cable plate shackle from the reaction vessel hull.

79

Figure 4-15. Explosive Lead Assembly.

NOTES:

1. INTERPRET DRAWING PER MIL-D-1000.

2. PRESS AT 10,000 PSI ± 100 PSI ONE INCREMENT OF 400 ± 4 MG RDX.

3. BOND ITEM 5 IN PLACE USING ITEM 6.

4. MARK PER ASD-5215M OR N WITH PART NUMBER 1215440-1.

.405 -.010 DIA

.005 ± .002 STOCK

-4 DETAIL

SEE -4 DETAIL

SEE -5 DETAIL

.750-16UNF-3A REF

2.906 REF

.250-18NPT REF

.269 DIA

-A-

.010 R MAX

.562

.408-.006 DIA

⊙ A Ⓜ .020 TIR Ⓜ

-5 DETAIL

AR	S8911			ADHESIVE	A-12	ARMSTRONG PRODUCTS CO., WARSAW, IND.		6
1				SLEEVE	-5	AL ALY 6061-T6	COML GRADE	5
1				DISC	-4	AL 1100-O SHEET		4
1		ACC MG		BOLT, EXPLOSIVE	1215440-1	RDX	MIL-R-398 TYPE B, CL C	3
1								2
-1				ASSEMBLY	-1			1
QTY REQ'D		SYM		NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO.	MATERIAL	SPECIFICATION	ITEM NO.
		CODE IDENT			PART OR IDENTIFYING NO.		UNIT WT. ZONE WT.	

LIST OF MATERIALS

Figure 4-16. Explosive Bolt Assembly.
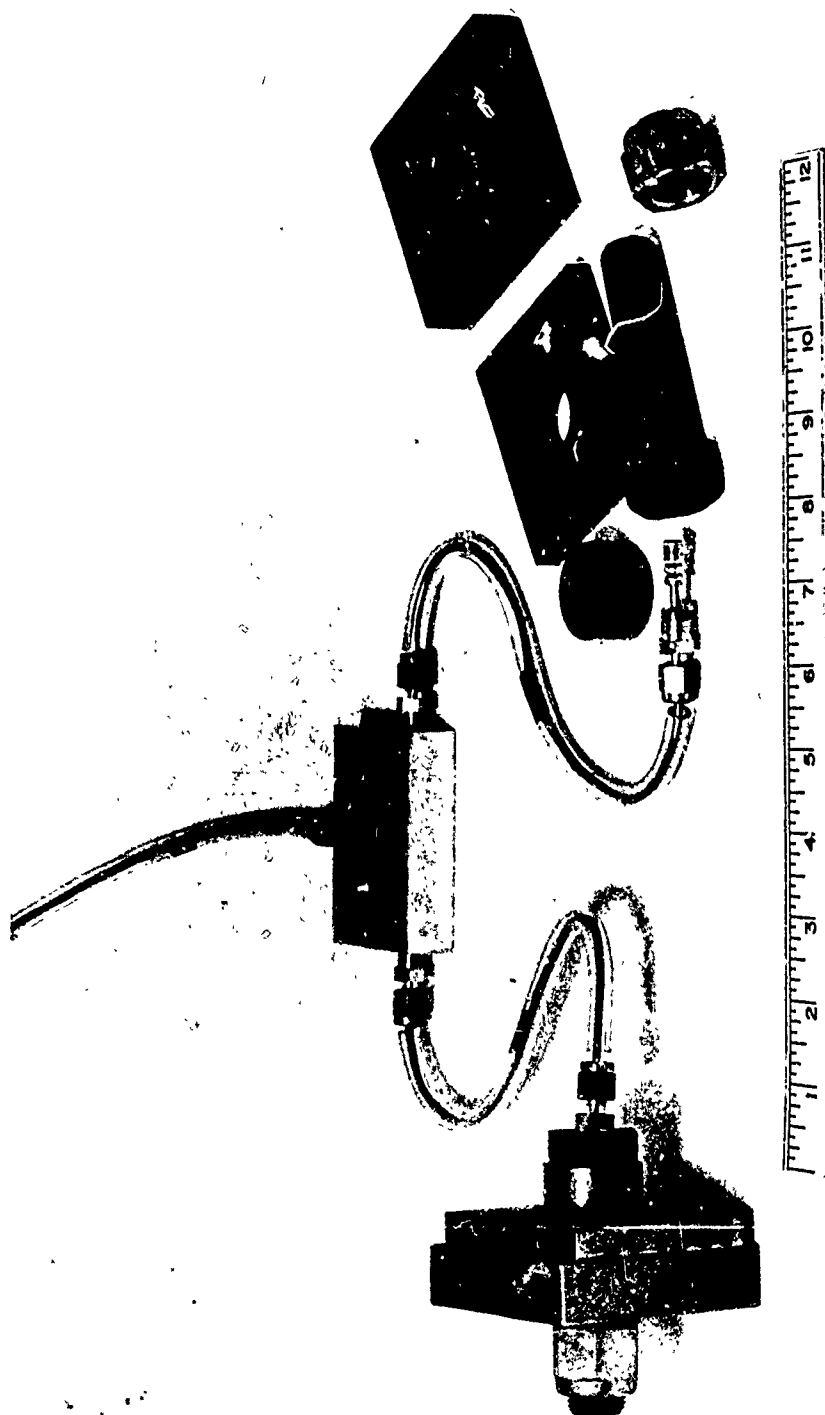
Figure 4-17. Separation System Components Before Testing.

268—191—1|
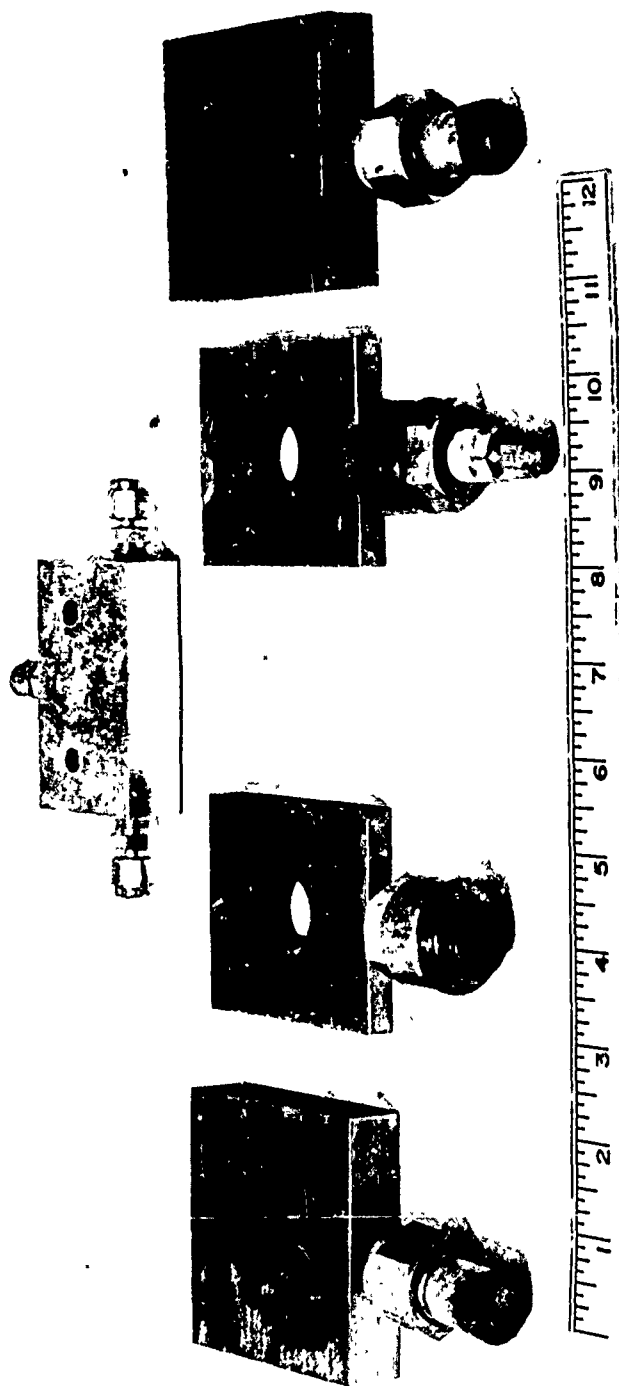
Figure 4-18. Separation System Components After Testing.

268-191-2

83

Section 5

FUNCTIONAL PERFORMANCE TESTS

General test operations began during the third week of January 1968 with the dry tests conducted at Fort Irwin, California. These tests are summarized in Paragraph 2.8. The water test operation began on a continuing basis in February 1968. These tests are summarized in Table 5-1. Fourteen test firings were conducted during the test program. For load measurements, a Navy-furnished, strain-gage-type load cell and a pen-type recording oscillograph were used. All load measurement tapes from the oscillograph were retained by NCEL; calibration of the load cell was accomplished and verified by NCEL.

The first series of three test firings was the dry tests described in Paragraph 2.8. The second series was five sand tests conducted in the vicinity of Port Hueneme, California. Maximum holding power for the sand anchor was in excess of 130,000 lb. The third series of three firings was mud tests conducted in San Francisco Bay. Maximum holding power was in excess of 92,000 lb. The fourth series of two firings was coral tests conducted at Key West, Florida. Sustained loads of 128,000 lb and surge loads of 136,000 lb were obtained.

5.1 SAND TESTS

5.1.1 Test No. 4

Test No. 4 was the first test firing to be conducted of the complete anchor system in the water. The test apparatus consisted of the standard launch vehicle (reaction vessel, barrel, and struts) and the sand anchor configuration projectile. The main propulsion charge consisted of 7 lb of M-6 propellant. The site selected for this test was on the left side of the jetty forming the entrance to the Port Hueneme harbor, in a water depth of 45 ft. The sediment composition was a uniform, medium-to-fine sand grain; however, core sample data were not available for this area. Testing was accomplished from the NCEL warping tug (Figure 5-1). Figure 5-2 is a general area view of the anchor on the tug being readied for firing, and Figure 5-3 shows the anchor just before entering the water. The propulsion system functioned normally upon command. Projectile penetration was 6 ft; the limited penetration is attributed to the reduced launch velocity, as expected. No holding power measurements were attempted. Because of the reduced

85

Table 5-i. Summary of Test Results.

Test No.	Test Date (1968)	Primer	Primary Igniter	Secondary Igniter	Main Load	Explosive Bolts	Penetration (ft)	Fluke Setting	Holding Force (lb)	Sediment	Location	Water Depth (ft)	Vessel	Remarks
1	23 Jan	2 each, X257H electrical	Pyrocore	150 gm, smokeless	7 lb, M-6	None	Not applicable	Not applicable	Not applicable	Not applicable	Fort Irwin	Not applicable	Not applicable	Internal pressure 9430 psi. Muzzle velocity 161 fps.
2	24 Jan	2 each, X257H electrical	Pyrocore	150 gm, smokeless	11 lb, M-6	None	Not applicable	Not applicable	Not applicable	Not applicable	Fort Irwin	Not applicable	Not applicable	Internal pressure 13,500 psi. Muzzle velocity 228 fps.
3	25 Jan	2 each, X257H electrical	Pyrocore	150 gm, smokeless	14 lb, M-6	None	Not applicable	Not applicable	Not applicable	Not applicable	Fort Irwin	Not applicable	Not applicable	No pressure data. Velocity 350 fps.
4	7 Feb	2 each, X257H electrical	Pyrocore	150 gm, smokeless	7 lb, M-6	None	6	Did not open		Medium sand	Port Hueneme, inside harbor jetty	45	NCEL warping tug	Flukes failed to open. All hardware recovered. Flukes were not free to rotate because of tight hinge points. Hinge points and hinge joints reworked.
5	13 Feb	2 each, X257H electrical	Pyrocore	150 gm, smokeless	9 lb, M-6	None	10	Two flukes opened	65,000	Medium sand	Port Hueneme, outside west jetty	40	NCEL warping tug	One fluke failed to open. All hardware recovered. Fluke hinge joint reworked. Reaction vessel damaged and returned to Fullerton for rework.
6	27 Feb	2 each, X257H electrical	Pyrocore	200 gm, smokeless	11 lb, M-6	2 each, PN 1215440	18	Unknown	No data	Medium sand	NCEL shallow water test area	35	YFU/NCEL warping tug	All hardware recovered. Flukes reworked by flaring tips 15°.
7	1 Mar	2 each, X257H electrical	Pyrocore	260 gm, smokeless	12 lb, M-6	2 each, PN 1215440	5	Did not open	No data	Medium sand	NCEL shallow water test area	35	YFU/NCEL warping tug	Piston lost during recovery operation
8	7 Mar	2 each, X257H electrical	Pyrocore	260 gm, smokeless	12 lb, M-6	None	No data	All flukes apparently opened	150,000-lb surge, in excess	Medium sand	NCEL shallow water test area	40	USNS Gear	One down-haul cable and one pendant cable broke in excess of 130,000 lb when ship surged in heavy ground swells. Anchor projectile lost, but piston was recovered.
9	16 Mar	2 each, X257H electrical	Pyrocore	260 gm, high velocity	4 lb, M-2	None	54 (estimated)	Unknown	78,000	Mud (clay)	San Francisco Bay	35	USNS Gear	All hardware recovered.
10	19 Mar	2 each, X257H electrical	Pyrocore	260 gm, high velocity	4 lb, M-2	None	12	Unknown	No data	Mud (clay)	San Francisco Bay	35	USNS Gear	All hardware recovered. Flukes reworked by flaring tips 15°.
11	21 Mar	2 each, X257H electrical	Pyrocore	260 gm, high velocity	6 lb, M-2	None	34	All flukes apparently opened	92,000	Mud (clay)	San Francisco Bay	35	USNS Gear	Socket on projectile end of down-haul cable failed. Excessive surge load broke second down-haul cable in excess of 92,000 lb.
12	28 May	X310J non-electrical	Pyrocore		4 lb, WC870	2 each, PN 1215440	8	Not applicable	68,000	Coral	Key West, 5 marker	~2	YFRT	Coral test anchor utilized. Complete ordnance system including safe/arm bolts, interline, etc. Original configuration projectile.
13	10 Jul	X310J non-electrical	Pyrocore		5 lb, WC870	2 each, PN 1215440	11	Not applicable	128,000 to 134,000 (surge)	Coral	Key West, Vestal Shoal	4	YSR-12	Coral projectile held 128,000 lb for 20 min, 134,000 lb for 10 hr required to extract projectile.

* Measured by NCEL.
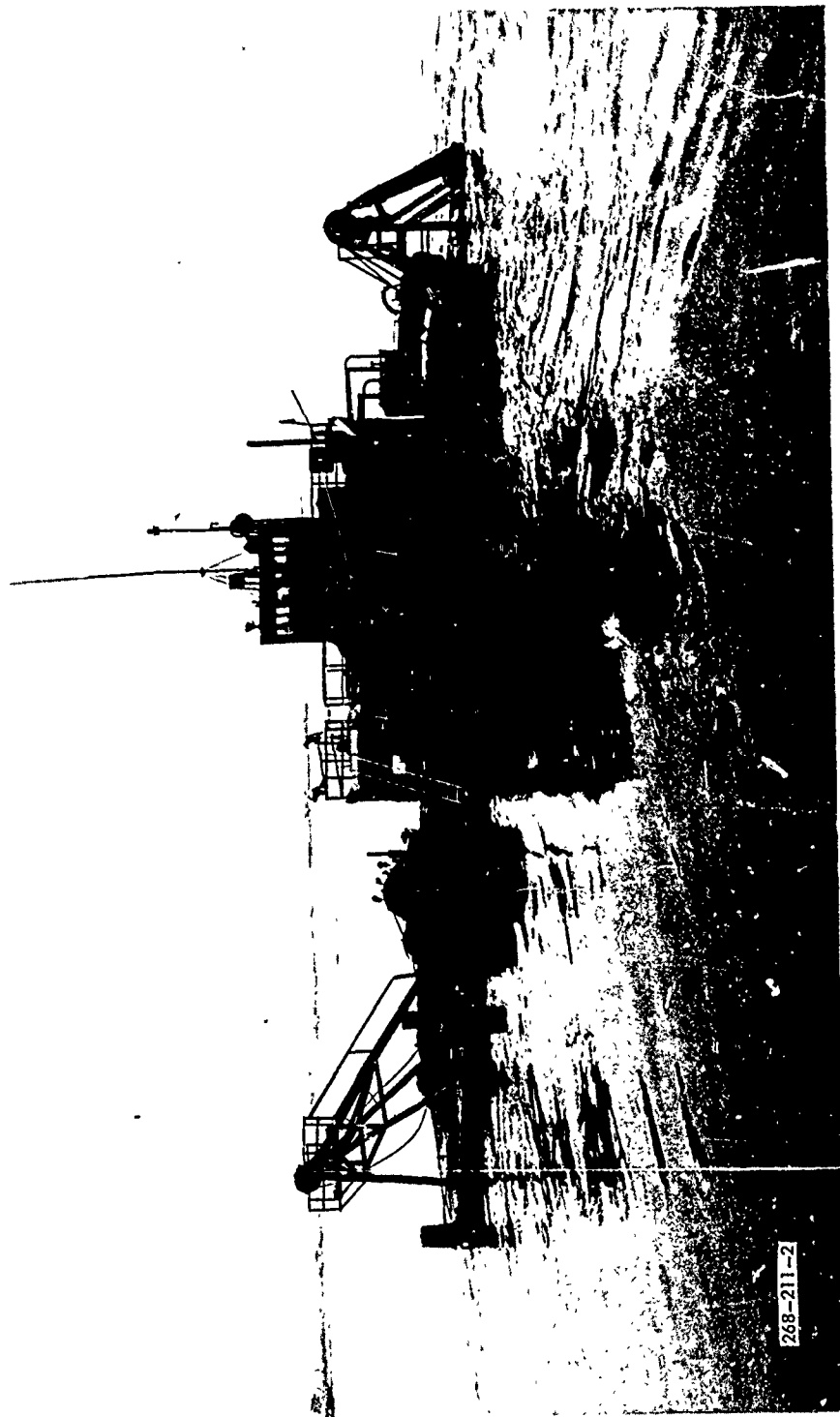
Figure 5-1. NCEL Warping Tug.
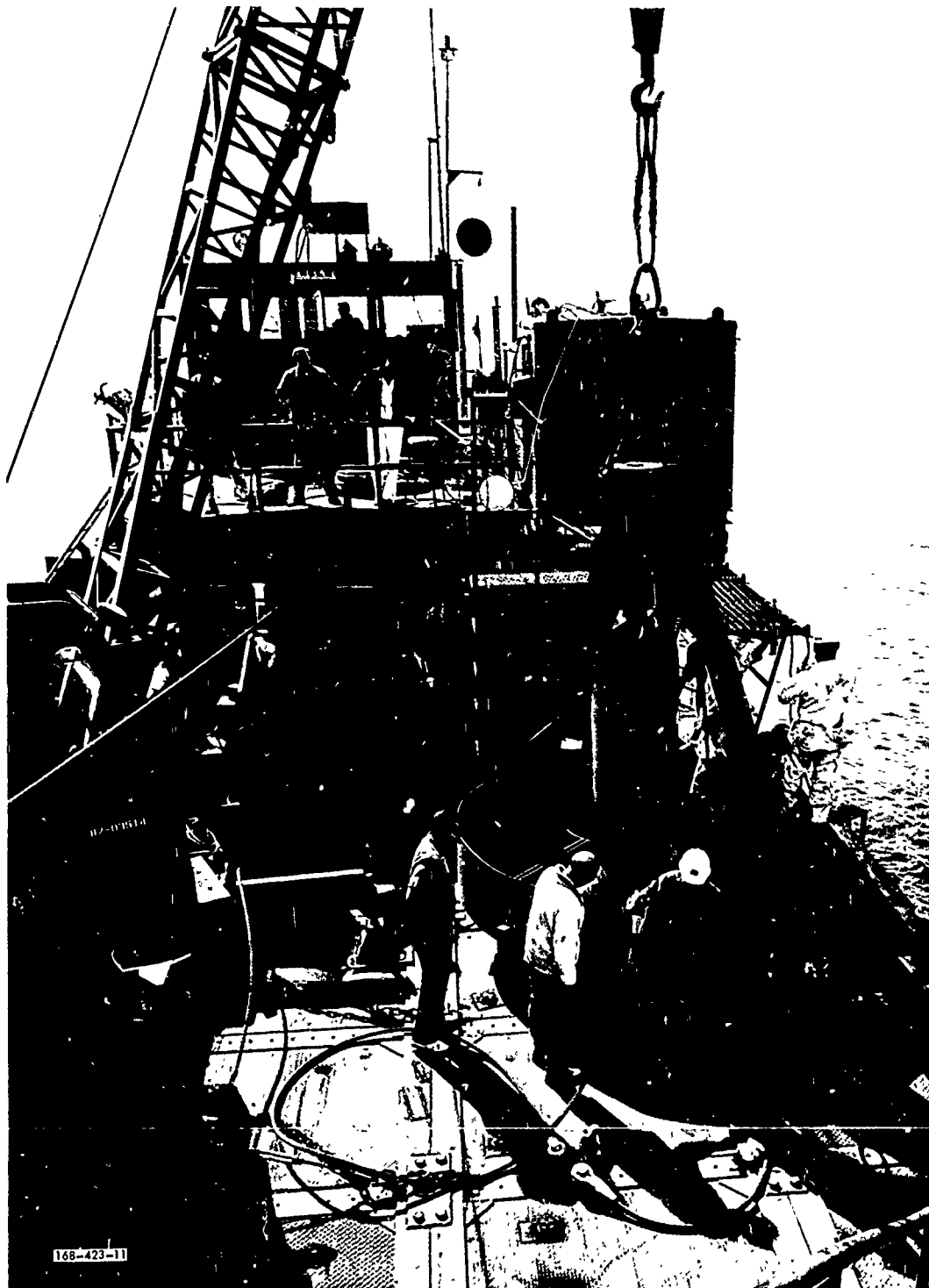
Figure 5-2. Anchor on Tug.

Figure 5-3.   Anchor Before Entering Water.

penetration, the flukes had not extended. The equipment was returned to the assembly building, where it was also determined that the fluke hinge joints were clogged with sand, which caused a close-tolerance hinge joint to seize. The hinge joint was reworked at the assembly building, and the equipment was readied for the next test operation.

5.1.2 Test No. 5

Test No. 5 consisted of firing a sand fluke configuration projectile from the standard launch vehicle. A total of 90 lb of M-6 propellant was used. The test site selected for this operation was 100 yd west of the west jetty of the Port Hueneme harbor. Water depth at the time of firing was 40 ft. The sediment was a uniform, round, medium sand grain of moderate bulk density. Core sample data were not available for this area. Anchor projectile penetration was 10 ft. Pull-testing was accomplished at 60° from the horizontal; breakout forces were measured at approximately 65,000 lb. The projectile was recovered, and it was observed that only two of the three flukes had deployed properly. High reaction loads caused significant deformation and weld-joint damage to the reaction vessel. The entire structure was returned to the Aerojet-Fullerton Facility for major rework. The refurbished reaction vessel, showing the added stiffener ribs, bulkheads, and double plates, is shown in Figure 5-4. Immediately after rework, the test apparatus was returned to Port Hueneme, where preparations were made for further test firings.

5.1.3 Test No. 6

In test No. 6, the sand fluke anchor configuration was launched from the modified reaction vessel assembly. A total of 11 lb of M-6 propellant was utilized in the main propulsion cartridge. A U.S. Navy vessel (YFU 37, under the cognizance of the Point Mugu Naval Missile Center) provided a working platform. Pull-testing was accomplished by the NCEL warping tug, shown in position in Figure 5-5; the warping tug is in position for pull-testing while the launch vehicle is being recovered. The site selected for this operation was 2 miles south of the Port Hueneme harbor entrance, and 300 yd offshore in 35 ft of water. Projectile penetration was 18.0 ft.

The NCEL load cell available was inoperative and failed to measure the breakout forces required to withdraw the anchor. Figure 3-12 shows the anchor projectile, with extended flukes, immediately after recovery. Because of difficulties in fluke deployment, it was necessary to flare the fluke tips to 15° for a distance of 18 in. back from the tip to enhance opening capability. The equipment was then readied for the next test in the series.
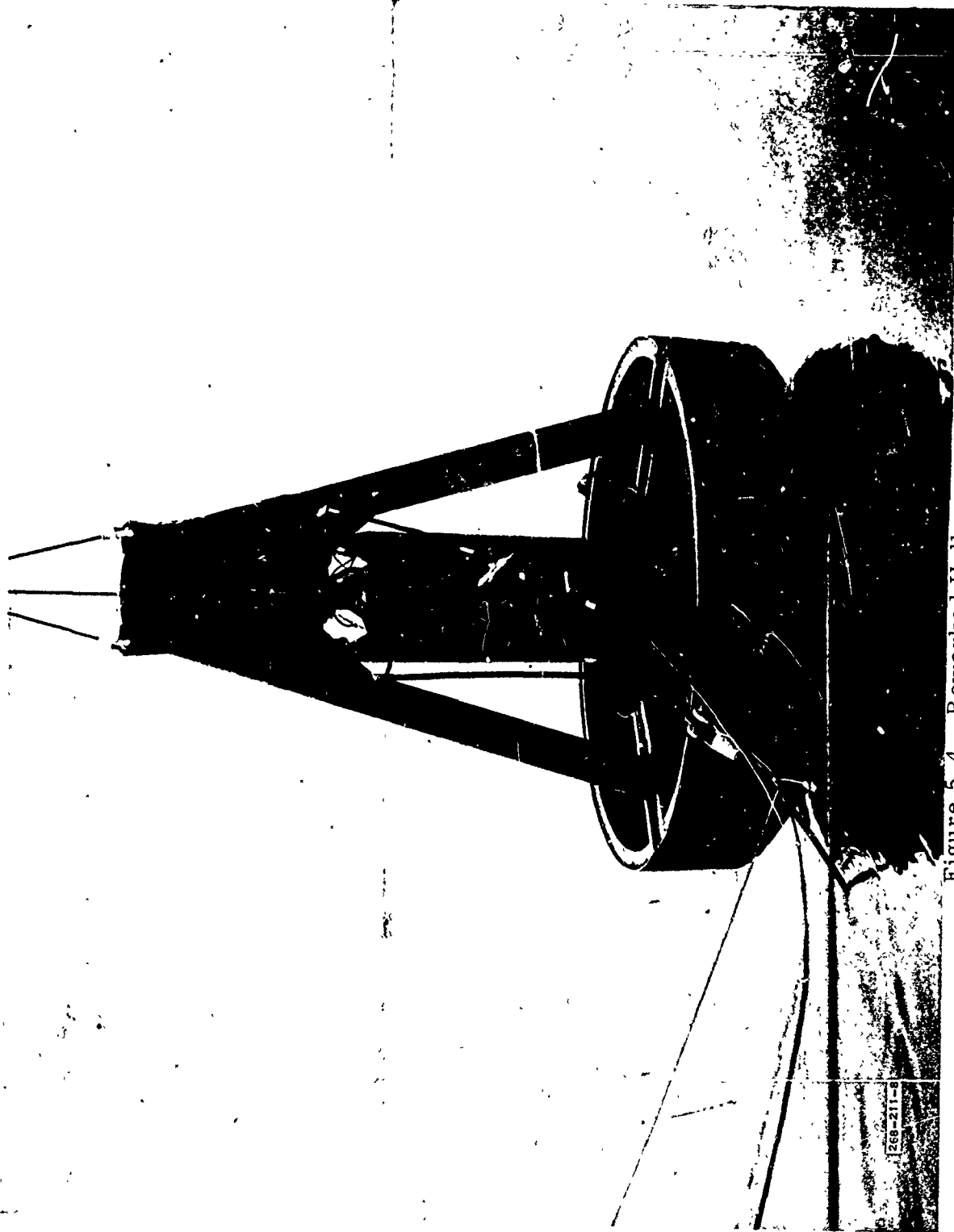
Figure 5-4. Reworked Hull.
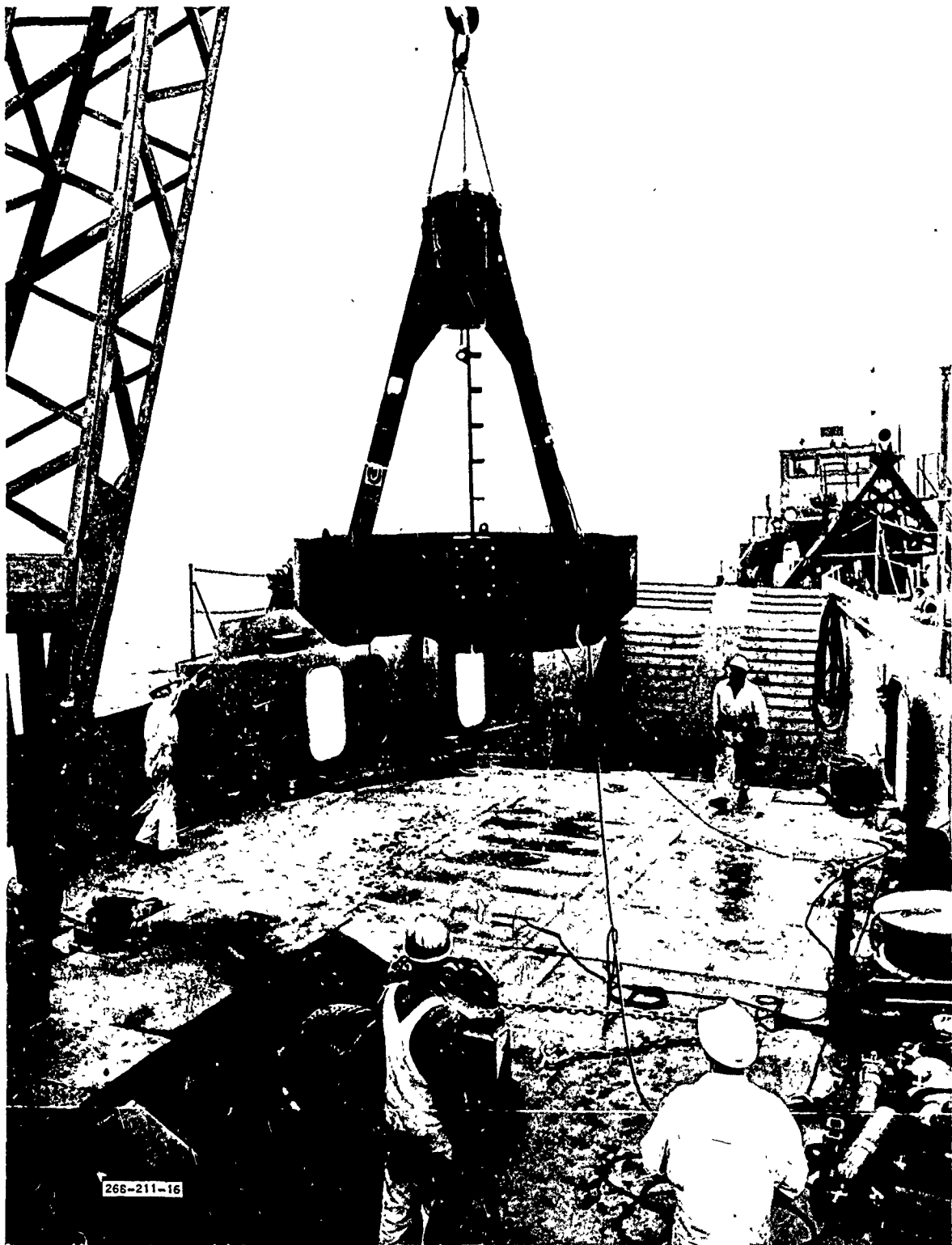
Figure 5-5. Reaction Vessel Recovery.

5.1.4 Test No. 7

In test No. 7, the modified sand flukes were fired with 12 lb of M-6 propellant. As in the preceding test, the YFU 37 was utilized as a working platform, and the NCEL warping tug was used for pull-testing. The test was performed in the same location as the preceding test (2 miles south of the harbor entrance and 300 yards offshore). Again, water depth at firing time was 35 ft. Projectile penetration was only 5 ft. This virtual nonpenetration may be attributed to sandstone formation immediately under the surface of the apparently sandy bottom, a reduced impact velocity, or both. However, no conclusive evidence was obtained. No holding power data were obtained from this test. The anchor piston was lost during recovery.

5.1.5 Test No. 8

Test No. 8 utilized the same modified sand fluke configuration and 12-lb propellant load as in the preceding test. The working platform for this operation was the USNS Gear (Figure 5-6). The test site was in the same general area as the two preceding tests. Water depth at test time was 40 ft. The anchor assembly was rigged and fired from this ship without difficulty (see Figure 5-7). However, because of unusually heavy seas, no attempt was made to measure projectile penetration. Pull-testing was accomplished at approximately 30° from the horizontal. All flukes apparently opened as required. The maximum load measured by the Navy-furnished load cell (Figure 5-8) was approximately 130,000 lb at the time the 1-1/4-in. downhaul cables parted during pull-testing. One of the cables broke 17 in. below the hull connector plate shackle (Figure 5-9), and the other cable broke 12 in. below the connector plate that coupled the 2-in. main tow wire to the projectile (see Figure 5-10). It is believed that heavy ground swells caused momentary surge loads in excess of 200,000 lb to be imposed on the cable system.

It should be noted that a steady-state load of 42,000 lb was imposed for a 2-hr period while preparations were being made for pull-testing and launch; The anchor exhibited no tendency to creep or otherwise withdraw during this period. Because of the rough water conditions, no attempt was made at that time to recover the lost hardware, and the site was marked with a buoy. However, subsequent attempts to locate the projectile were unsuccessful. Only the piston, which was lying on the bottom, was located and recovered.
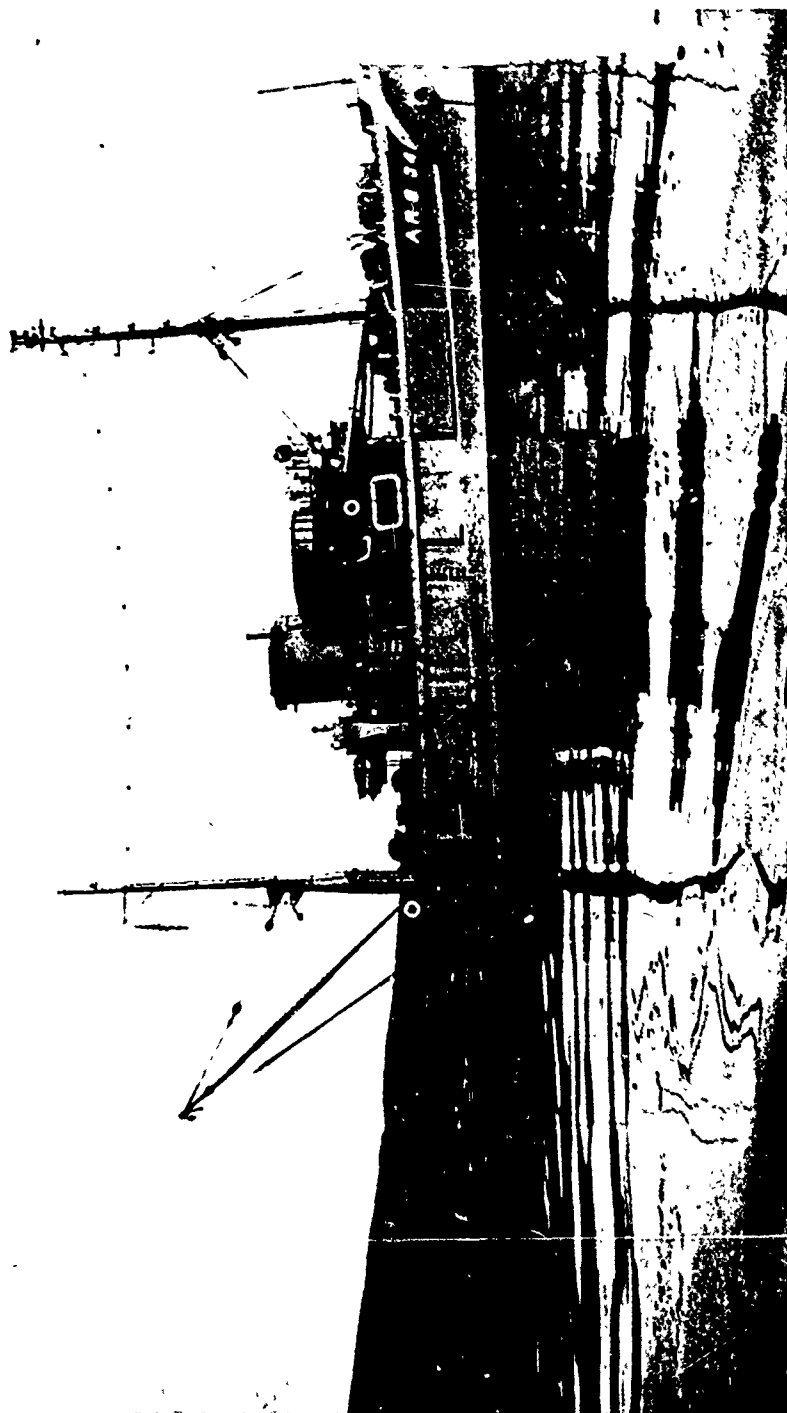
Figure 5-6. USNS Gear.
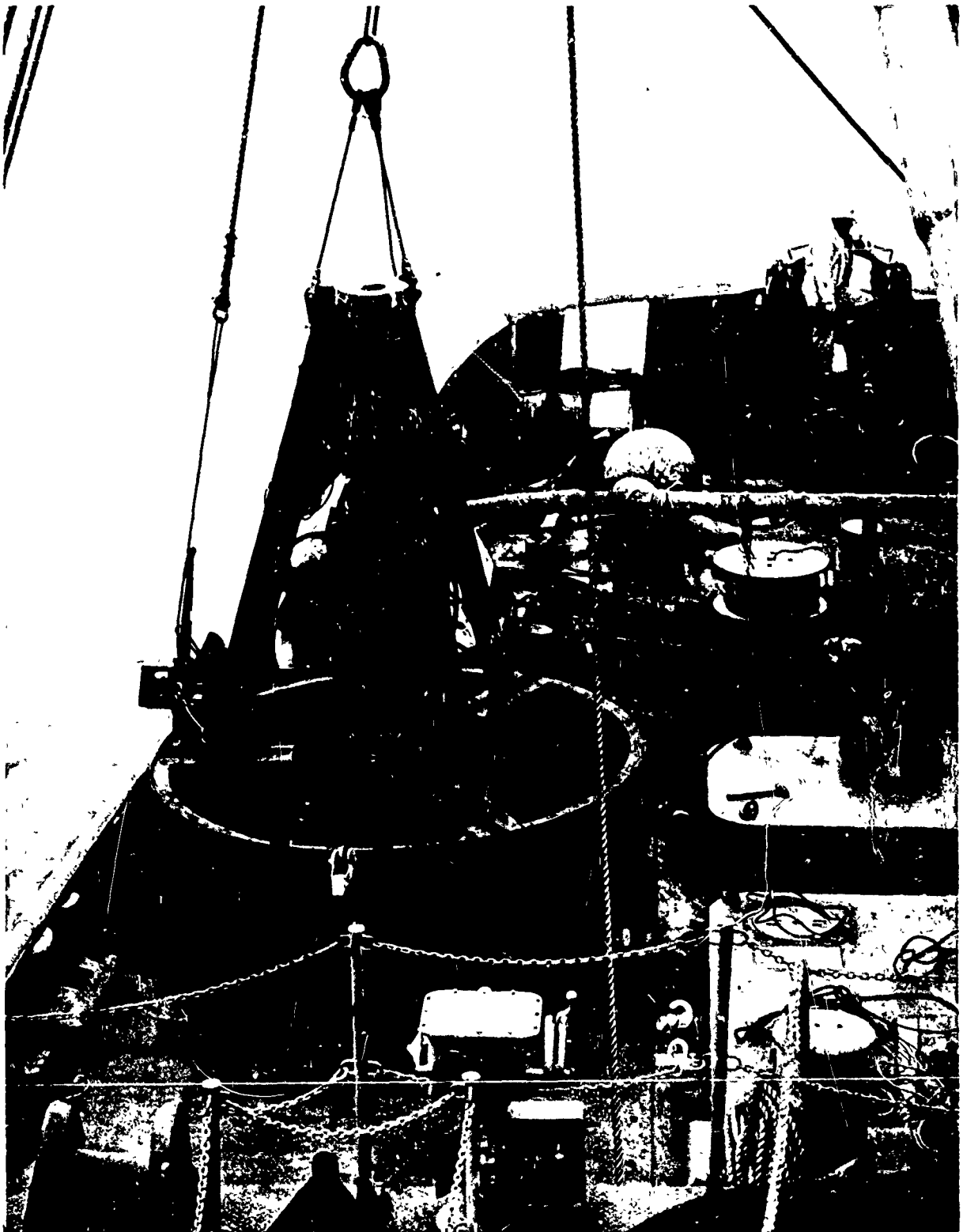
Figure 5-7.   Anchor Assembly Aboard USNS Gear.
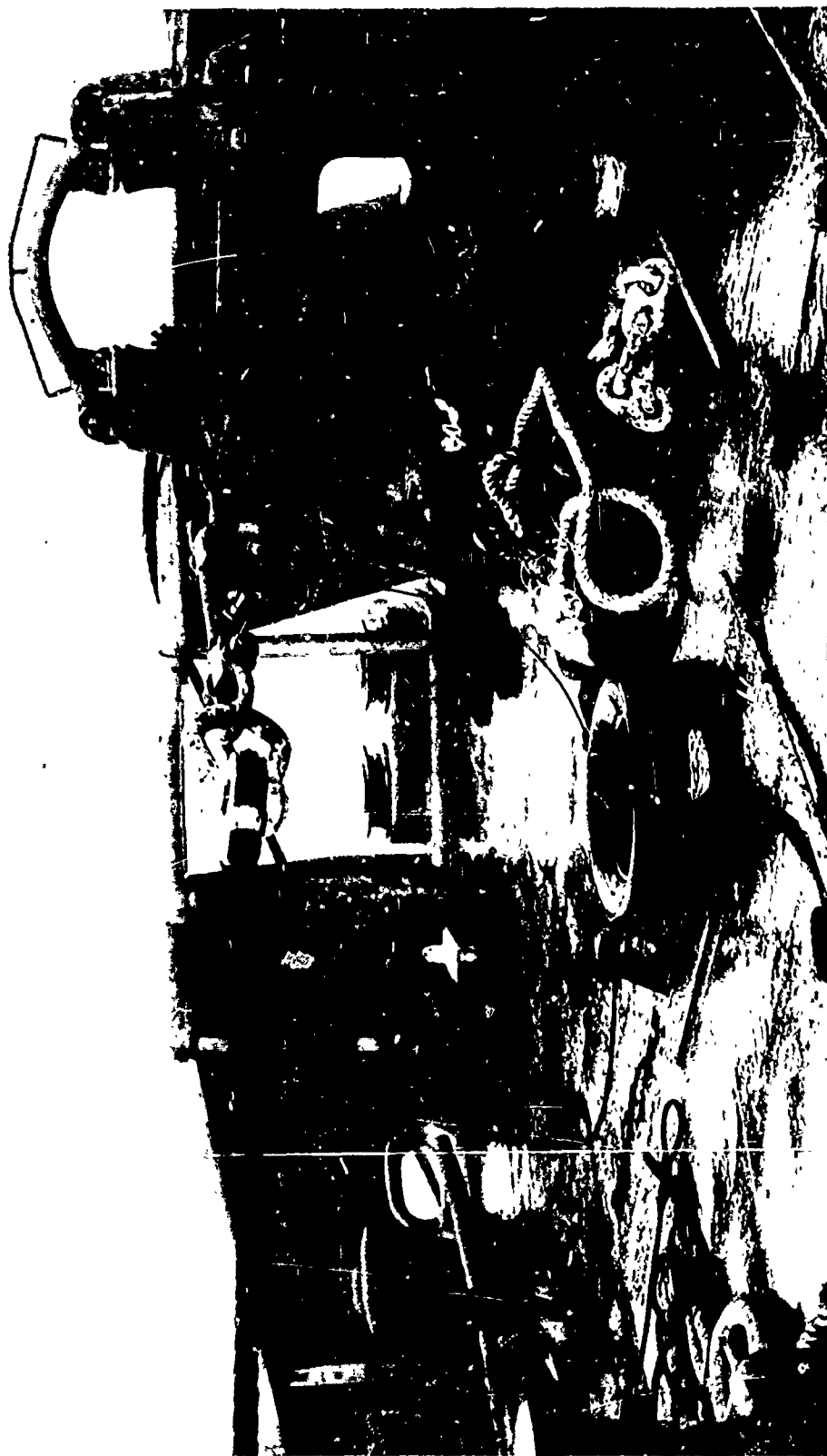
Figure 5-8. Navy-Furnished Load Cell.

Figure 5-9.   Break in Cable 17 in. Below Hull Connector Plate Shackle.

Figure 5-10. Break in Cable 12 in. Below Connector Plate.

OFFICIAL PHOTOGRAPH, U.S. NAVY

98

5.2   MUD TESTS

5.2.1   Test No. 9

Test No. 9 was the first to be conducted in San Francisco Bay. The selected site was 300 yd south of Pier 3 at the Hunters Point Naval Shipyard, in 35 ft of water. This test combined the mud fluke configuration anchor, shown in Figure 5-11, and a 4-lb M-2 propellant charge.

The USNS Gear was again used for this operation. Test firing was accomplished without incident. Penetration was estimated as 54 ft, but the estimate is questionable because of extremely dirty water, high tidal currents, and generally zero visibility which made reliable visual observations difficult. Core sample data were not available for this area.

A load of approximately 78,000 lb applied at 30° from the horizontal was required to pull the anchor free. Approximately 45,000 lb of holding capability was maintained for 3 hr while the ship was being made ready for pulling and beach gear was being rigged.

5.2.2   Test No. 10

Test No. 10 was also conducted in San Francisco Bay. A total of 4 lb of M-2 propellant was used in the propelling charge, and the mud flukes were reworked for the test by flaring the tips 15°. Penetration was measured at 12 ft; no core sample data were available   Relatively little force was required to withdraw the projectile. The flukes were fully extended when the projectile was recovered, as shown in Figure 5-12.

5.2.3   Test No. 11

Test No. 11 utilized 6 lb of M-2 propellant to launch the mud anchor. Penetration was measured at 34 ft, in a predominantly clay composition bottom. No core sample data were available. The down-haul cables failed at the time a total holding power of 92,000 lb was being measured. In the first failure, the down haul socket attached to the projectile was twisted off the attachment boss, as shown in Figures 5-13 and 5-14. The resulting surge load, although applied through an equalizing thimble, caused the other down-haul cable to part 18 in. above the attachment point on the projectile. The load was being applied at an angle of 30° from the horizontal at the time of failure.
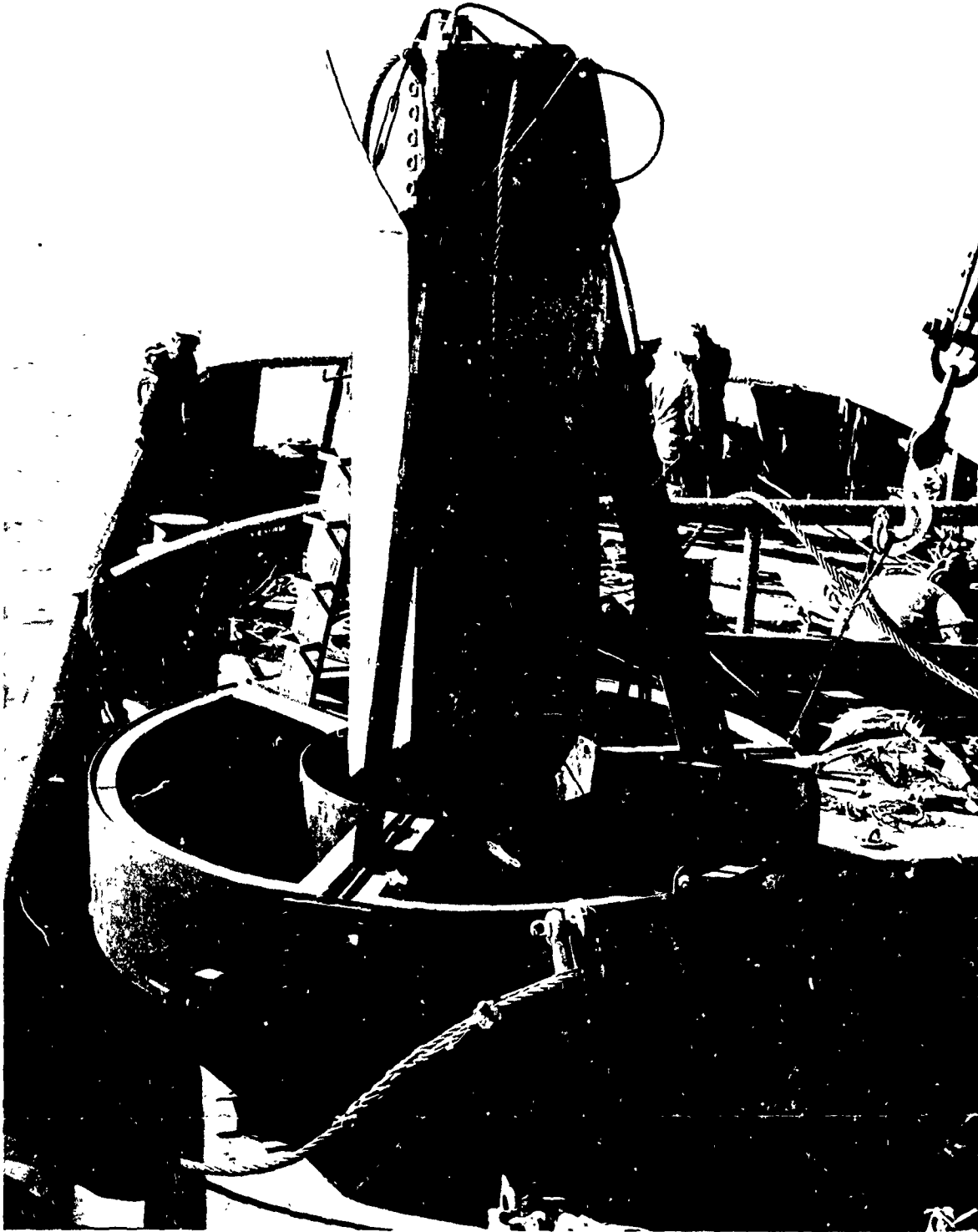
Figure 5-11. Mud Fluke Configuration Anchor.
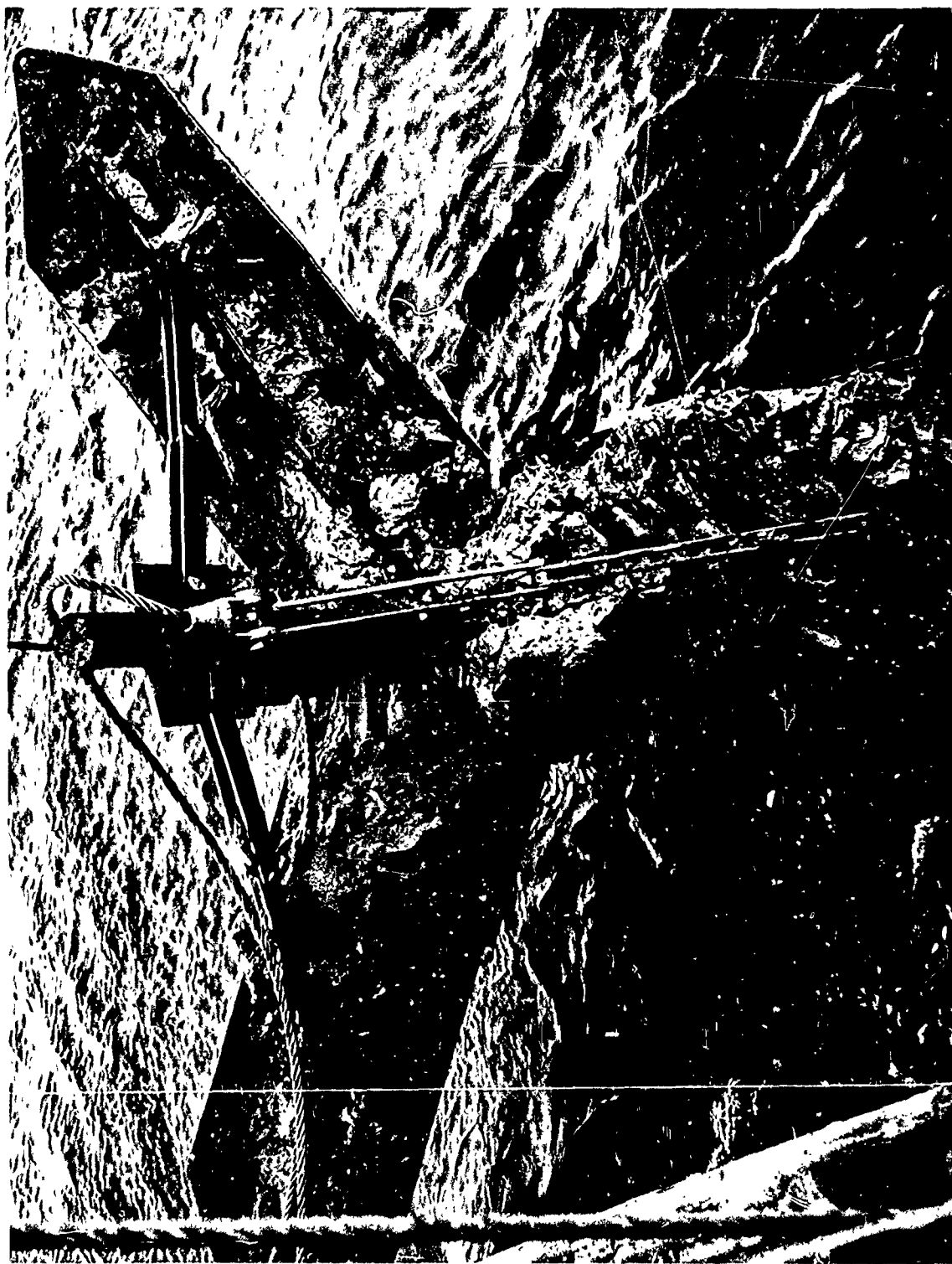
Figure 5-12. Flukes Fully Extended on Recovery.

Figure 5-13. Down-Haul Socket Shown Twisted off Attachment Boss.

Figure 5-14. Down- Haul Socket Twisted Off Attachment Boss.

5.3 CORAL TESTS

5.3.1 Test No. 12

Test No. 12 was the first test to be conducted in coral at Key West, Florida. The selected site was in 52 ft of water approximately 3700 yd WSW of Western Sambo Shoal at the "J" marker, which is located 7 nautical miles south of Key West. This test operation incorporated the experimental model coral penetrator, as shown in Figure 5-15, and a 4-lb WC870 propellant charge.

A Navy-operated YFRT, under the cognizance of the Naval Ordnance Unit at Key West, was utilized as a surface support vessel. Test firing was accomplished under inclement weather conditions without incident. The test utilized the full anchor propulsion subsystem, which included safe/arm device, explosive bolts, MDF ordnance interlinkage, production firing cable, and firing panel.

Anchor penetration into the coral sea-floor formation was 8 ft. Pull-testing was accomplished at approximately 30° from the horizontal by two Navy harbor tugs. The maximum load measured by a Navy-furnished load cell was 68,000 lb at anchor breakout. The test projectile was recovered and returned to the Naval Ordnance Unit shops for modification. A similarly modified coral projectile is shown in Figure 5-16.

5.3.2 Test No. 13

Test No. 13 was also a coral anchor test conducted in the vicinity of Key West. The specific area selected was approximately 2600 yd SW of Vestal Shoal, which is approximately 14 nautical miles SW of Key West harbor. The water depth was approximately 45 ft.

In this test operation, the USS Penguin (ASR-12), under the cognizance of SubRon-12, was utilized for the surface support vessel. Test operations were carried out without incident in accordance with Aerojet Test Procedure AD 3324-01(A)-TP (Appendix G). The test apparatus consisted of the standard launch vehicle and incorporated the modified coral penetrator anchor, as shown in Figure 5-17. The sea floor was composed of a live coral reef of undetermined thickness. However, coral material samples obtained from disintegrated rubble at the point of impact indicated that the coral material had an ultimate compressive strength of 3500 psi and a specific density of 20 gm/cc. Photographs of some typical coral material, illustrating the characteristic porosity, are shown in Figures 5-18 and 5-19.
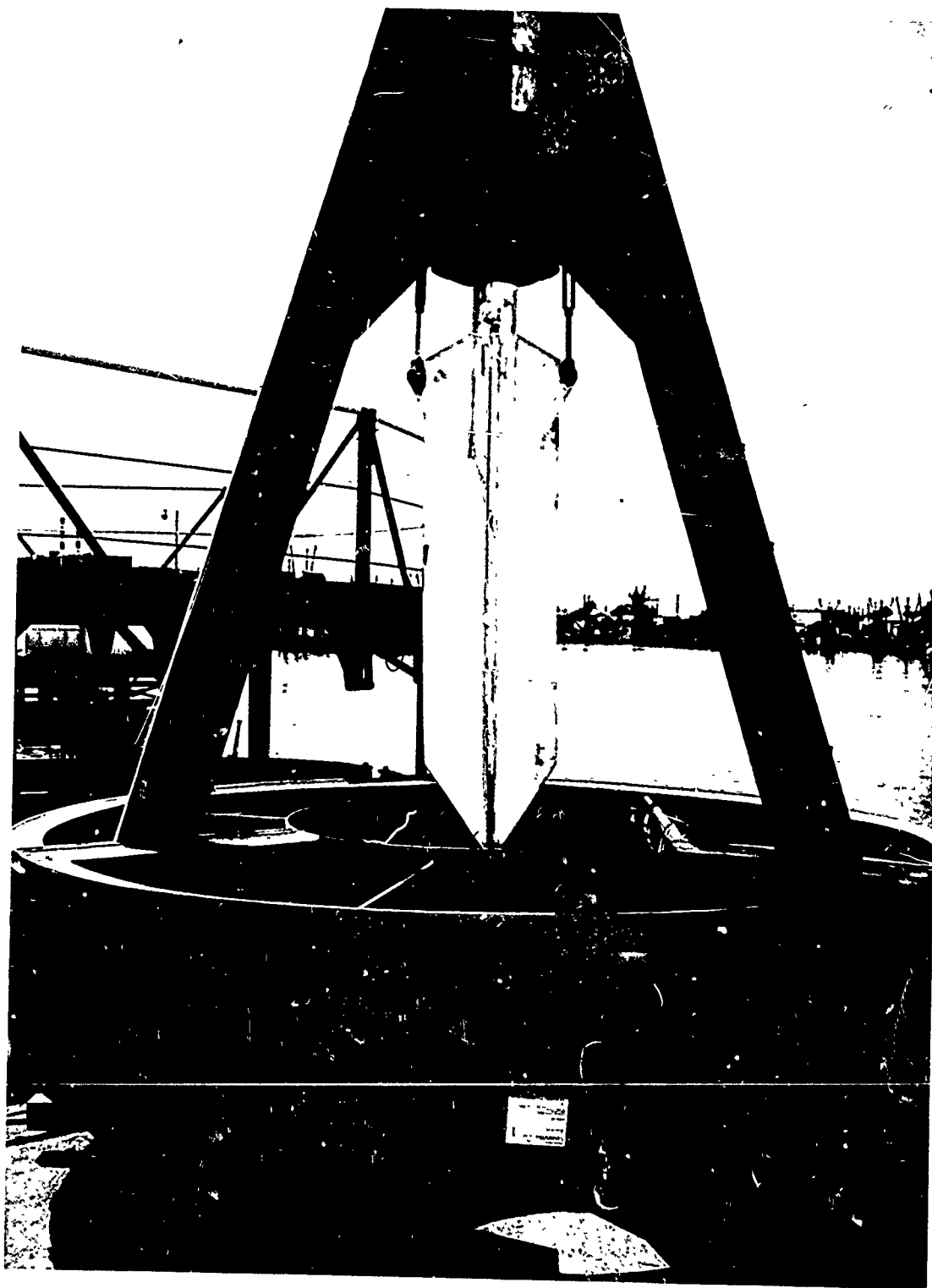
Figure 5-15.   Coral Penetrator Experimental Model.

OFFICIAL PHOTOGRAPH, U.S. NAVY
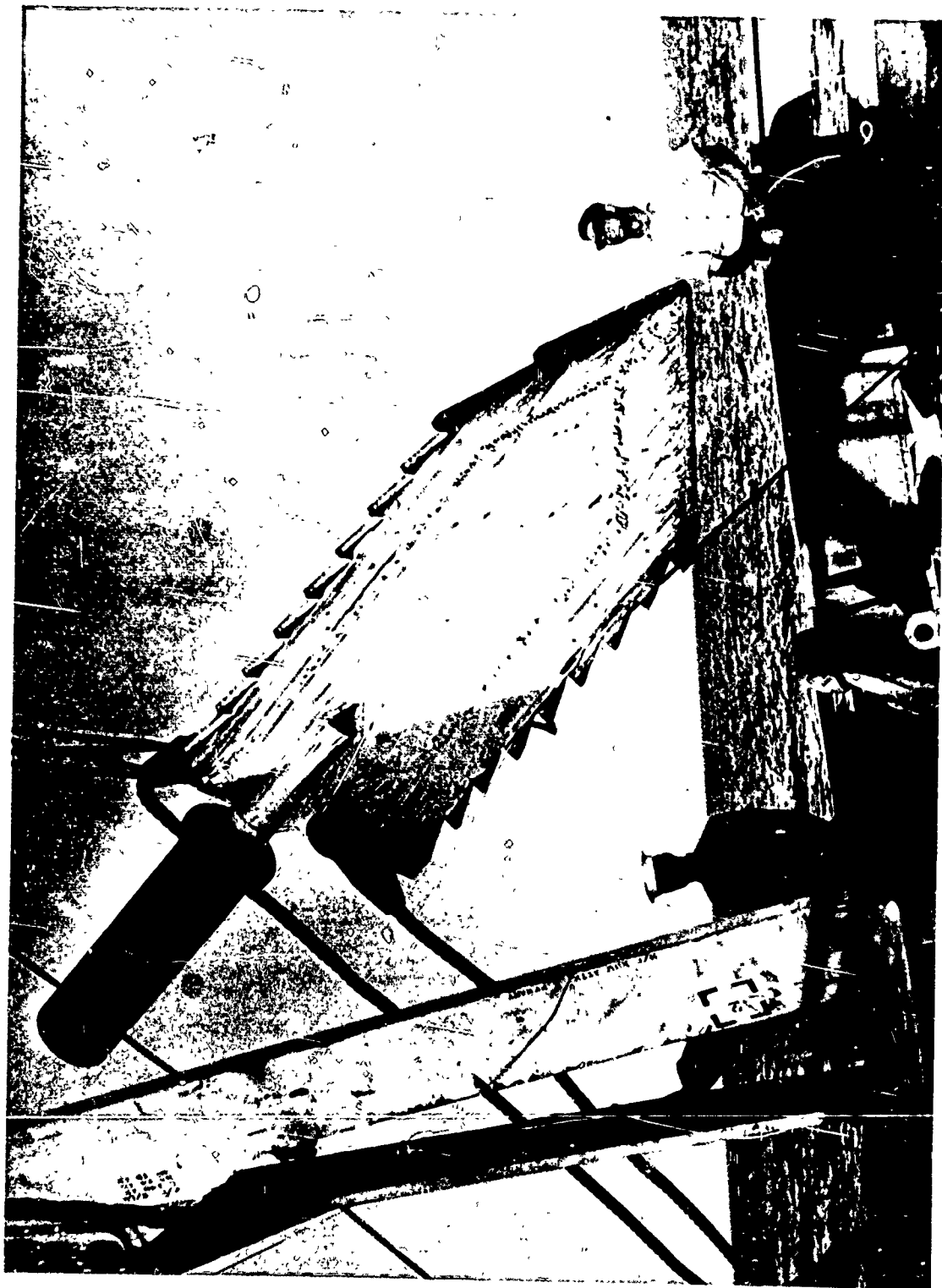
Figure 5-16.   Modified Coral Projectile.

106
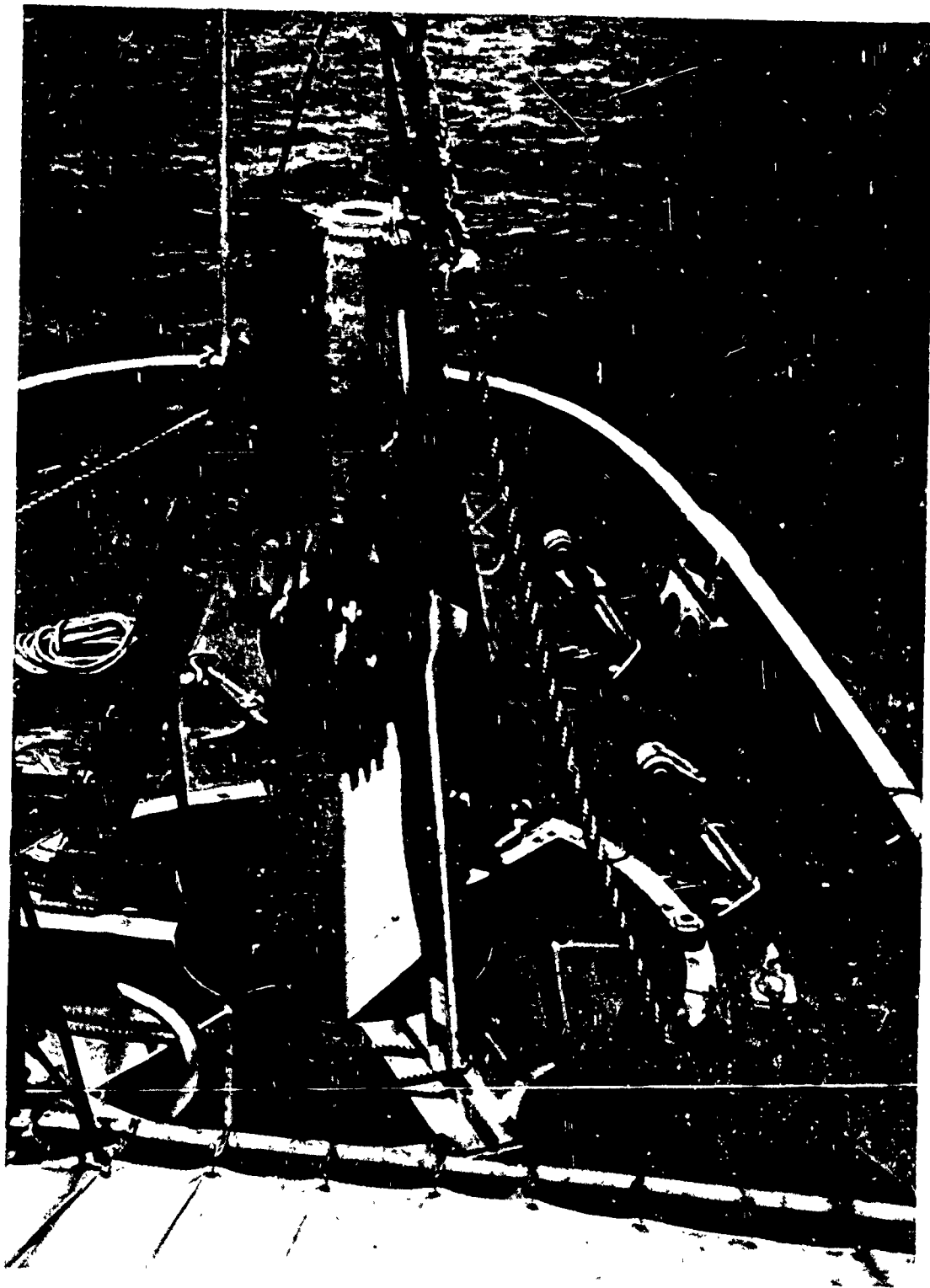
Figure 5-17. Modified Coral Penetrator Anchor.

Figure 5-18. Typical Coral Material.

Figure 5-19. Typical Coral Material.

688-175-6

The main propulsion system charge utilized 5 lb of WC 870 propellant, initiated on command from the surface support vessel. The propulsion system functioned normally, and penetration was 11 ft. Pull-testing was accomplished by ASR-12, as illustrated in Figure 5-20, with assistance from two harbor tugs (Figure 5-21). The pull angle was 25° from the horizontal. Sustained holding power loads of 128 000 lb were obtained for approximately 20 min, with surge loads of up to 136,000 lb. The anchor could not be pulled free under this mode of loading.

Consequently, in order to free the embedded projectile, the ship was positioned so that the main tow wire led vertically over the stern roller to the anchor below. Approximately 35,000 to 40,000 lb of load was applied by the capstans and secured. Ten hours of sustained vertical load in this manner was required to free the anchor. The recovered anchor projectile is shown in Figure 5-22.

This test operation concluded the Aerojet test program. NCEL assumed cognizance of the anchor test vehicle to conduct further tests.
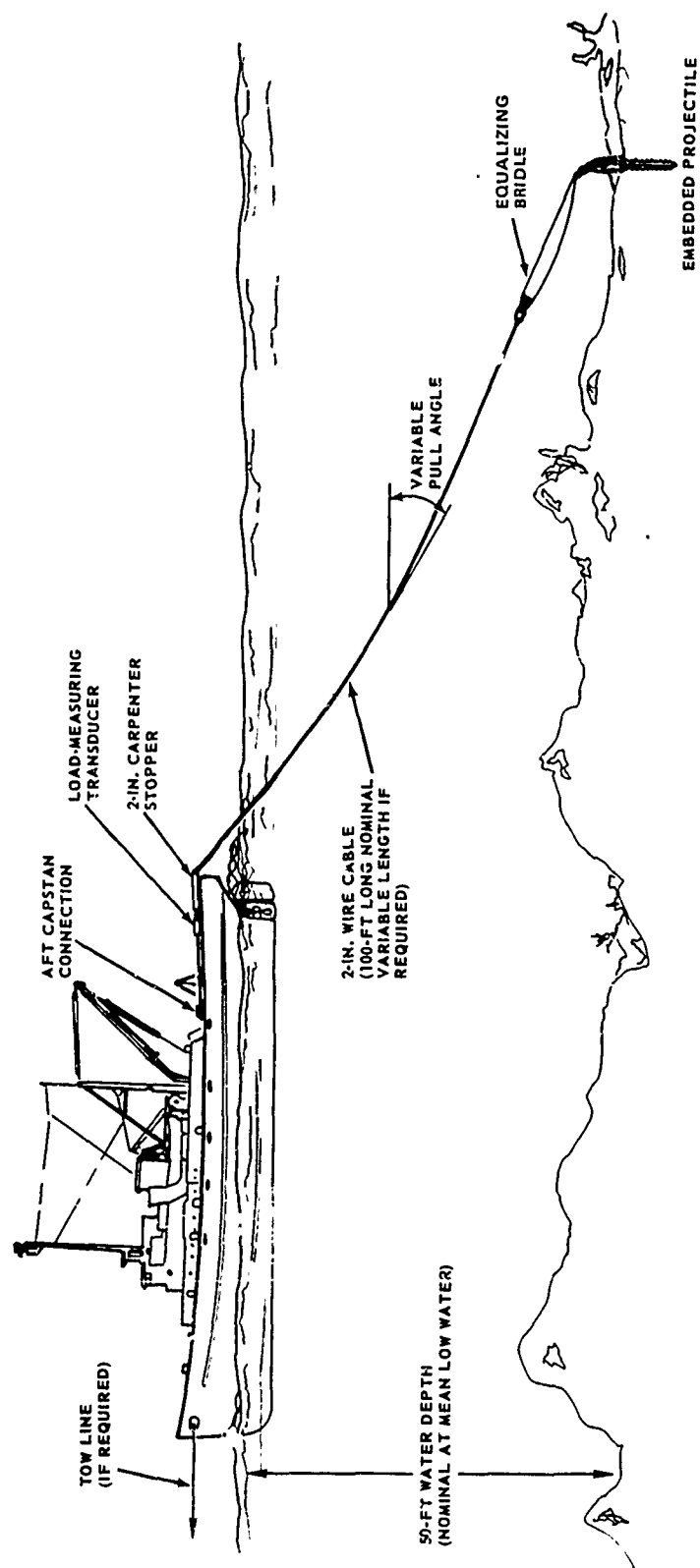
Figure 5-20. Holding Power Test Arrangement.

EMBEDDED PROJECTILE

EQUALIZING
BRIDLE

VARIABLE
PULL ANGLE

LOAD-MEASURING
TRANSDUCER

2-IN. CARPENTER
STOPPER

AFT CAPSTAN
CONNECTION

2-IN. WIRE CABLE
(100-FT LONG NOMINAL
VARIABLE LENGTH IF
REQUIRED)

TOW LINE
(IF REQUIRED)

50-FT WATER DEPTH
(NOMINAL AT MEAN LOW WATER)

111
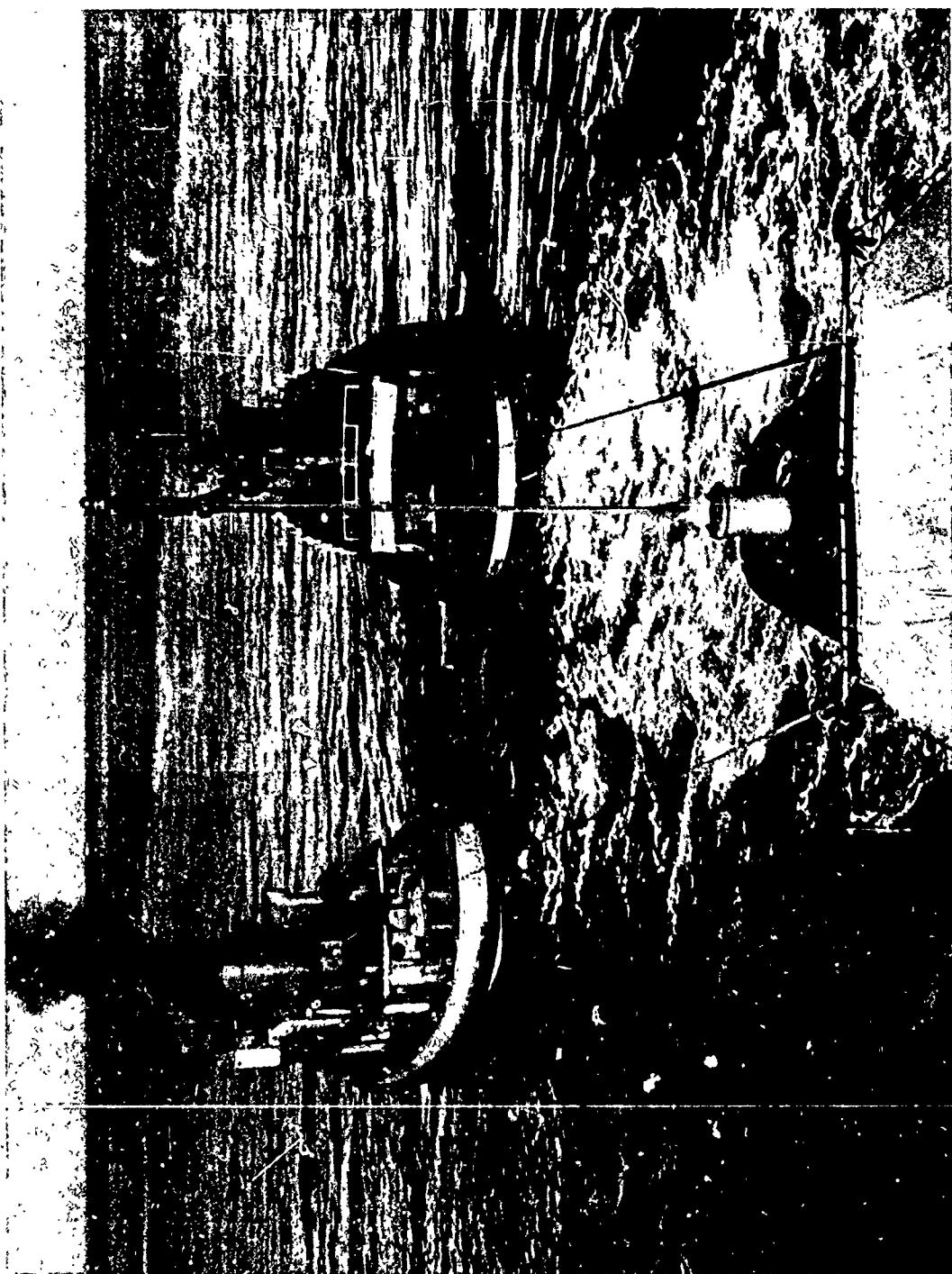
Figure 5-21. Harbor Tugs During Pull Testing.
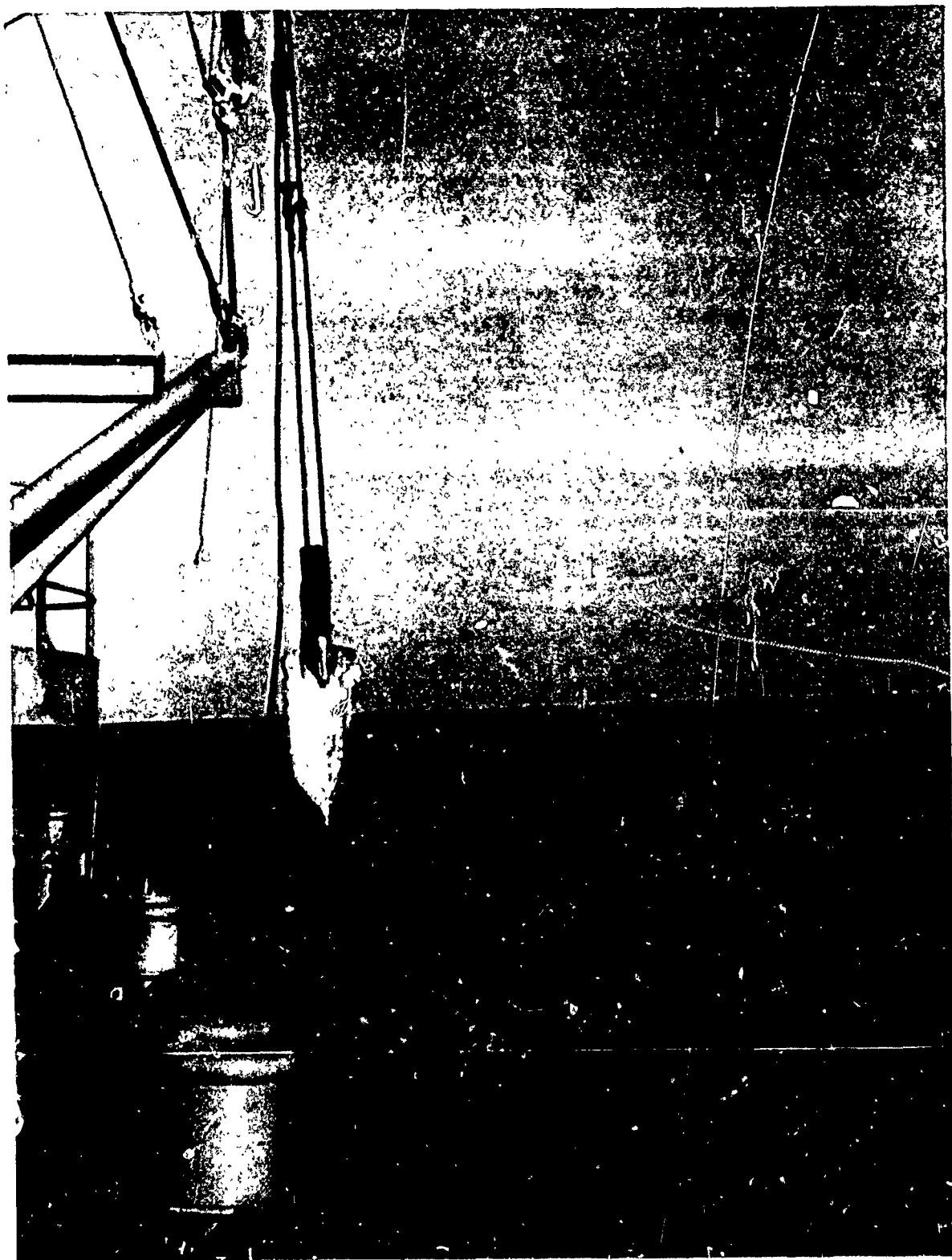
Figure 5-22. Anchor Projectile After Recovery.

113

Appendix A

INTERIOR BALLISTICS

A-1. BALLISTIC EQUATIONS

The interior-ballistic equations in closed form, which relate projectile travel (L) and velocity (V) to instantaneous gun pressure (P), are as follows:

For an unconstrained charge

$$m' = (1 + f) \left(1 + \frac{C}{3 W_o}\right) \frac{W_o}{g} \tag{1}$$

m' = effective projectile mass (slugs)

f = projectile friction and spin loss

C = charge weight (lb)

W_o = projectile weight (lb)

g = gravity constant (32.2 fps^2)

$$m'_r = (1 + f_r) \frac{W_r}{g} \tag{2}$$

m_r = effective recoil mass (slugs)

f_r = recoil friction and spin loss

W_r = recoil weight (lb)

$$\mu = \frac{m'}{m'_r} \tag{3}$$

μ = ratio of effective projectile mass to effective recoil mass

A-1

$$V_b = \frac{A\, w_o}{m'\, 2\, c'} \qquad\qquad (4)$$

V_b = burnout velocity (fps)

A = bore area (sq in.)

w_o = web thickness (in.)

c' = propellant burning rate coefficient (ips/psi)

$$e_2 = \frac{C\, F\, (1 + r')}{m'\, V_b} \qquad\qquad (5)$$

e_2 = ballistic constant (fps)

F = propellant impetus (ft-lb/lb)

r' = propellant regressiveness

$$\bar{\gamma} = 1 + (1 + \beta)\, (\gamma - 1) \qquad\qquad (6)$$

$\bar{\gamma}$ = pseudoratio of specific heat

β = fraction heat loss

γ = measured ratio of specific heat

$$u = \frac{(\bar{\gamma} - 1)\, (1 + \mu)}{2} + \frac{C\, F\, r'}{m'\, V_b^2} \qquad\qquad (7)$$

u = ballistic constant

$$Z = \frac{V}{e_2} \tag{8}$$

Z = dimensionless velocity

V = velocity (fps)

$$J = (1 - u\,Z)^{-\frac{1+\mu}{u}} \tag{9}$$

J = ballistic parameter (dimensionless)

$$X_o = \frac{V_c}{A} \tag{10}$$

X_o = effective length of chamber (in.)

V_c = chamber volume (cu in.)

$$a = \frac{C}{\rho\,V_c} \tag{11}$$

a = volumetric loading

ρ = propellant density (lb/cu in.)

$$Z_b = \frac{V_b}{e_2} \tag{12}$$

Z_b = dimensionless velocity at burnout

A-3

$$a_1 = (n\rho - 1)(1 + r') \frac{a}{Z_b} \tag{13}$$

a_1 = ballistic constant (dimensionless)

n = propellant covolume (cu in. /lb)

$$S = \frac{J - (1 - uZ)}{1 + \mu + u} \tag{14}$$

S = ballistic parameter (dimensionless)

$$a_2 = \frac{(n\rho - 1) r' a}{Z_b^2} \tag{15}$$

a_2 = ballistic constant (dimensionless)

$$L = \frac{X_o}{1 + \mu} \left\{ (J-1)(1-a) - a_1(S-Z) + a_2 \left[\frac{2S}{1 + 2u + \mu} - \frac{2Z(1-uZ)}{1 + 2u + \mu} - Z^2 \right] \right\} \tag{16}$$

L = projectile travel (in.)

$$e_3 = \frac{12 \, m' \, e_2^2}{V_c} \tag{17}$$

e_3 = ballistic constant

A-4

$$P = \frac{e_3 \, Z \, (1 - uZ)}{J \, (1-a) - a_1 \, S + a_2 \left[\dfrac{2S}{1 + 2u'\mu} - \dfrac{2Z \, (1 - uZ)}{1 + 2u + \mu} \right]} \qquad (18)$$

P = pressure (psi)

$$X = X_o + (1 + \mu) \, L \qquad (19)$$

X = projectile travel plus effective chamber length (in.)

After burnout

$$m'_o = (1 + f) \left(1 + \frac{C}{3 \, W_o} \right) \left(\frac{W_o}{g} \right) \qquad (20)$$

m'_o = effective projectile mass after burnout

$$a_o = \frac{2A \, P_b \, (X_b - n \, C/A)}{12 \, m'_o \, V_b^2 \, (\bar{\gamma} - 1) \, (1 + \mu)} \qquad (21)$$

a_o = ballistic parameter

$$X_m = X_o + (1 + \mu) \, L_m \qquad (22)$$

X_m = effective chamber length plus barrel length (in.)

L_m = barrel length (in.)

A-5

$$V_m = V_b \left\{ 1 + a_o \left[1 - \left(\frac{X_b - n\,C/A}{X_m - n\,C/A} \right)^{\bar{\gamma} - 1} \right] \right\}^{1/2} \tag{23}$$

V_m = muzzle velocity (fps)

$$P_m = P_b \left(\frac{X_b - n\,C/A}{X_m - n\,C/A} \right)^{\bar{\gamma}} \tag{24}$$

P_m = muzzle pressure (psi)

A-2. COMPUTER RUNS AND CURVES

Computer runs for both the sand and mud anchor cases are included in the following pages. The sand anchor computations are for 10, 12, 14, and 16 lb of M-6 propellant charge. The output columns give anchor velocity, piston travel relative to the barrel, barrel travel relative to the piston, reaction vessel velocity, anchor travel, pressure, and piezometric efficiency. Tabulated output is presented. A similar output for the mud anchor with 2, 4, 6, and 8 lb of M-2 propellant charge is also given.

Curves of charge weight versus muzzle velocity and peak pressure are given in Figures A-1 and A-2, respectively, for the sand and mud anchor conditions. A curve of anchor velocity and pressure versus piston travel (relative to the barrel) for the sand anchor with a typical charge of 14 lb is given in Figure A-3. A similar curve for the mud anchor with a 6-lb charge is given in Figure A-4, and for the coral anchor in Figures A-5 and A-6.

A-3. BARREL STRESS CALCULATIONS

The anchor barrel and piston configuration is shown schematically in Figure A-7. It can be seen that both the barrel and piston must be capable of withstanding the peak ballistic pressure. The piston must withstand the peak pressure over its entire length, while the barrel may be tapered toward the muzzle. An untapered barrel was selected for ease of fabrication, somewhat lower cost, and added reaction vessel weight.

A-6

ANCHOR BALLISTICS SAND PROJECTILE WITH 10 LB M6 CHARGE

V	(1+MU)*L	MU*L	MU*V	L	P	H
0.200000E 02	0.140344E 01	0.242106E 00	0.41?344E 01	0.116133E 01	0.418718E 04	0.487892E 00
0.400000E 02	0.302822E 01	0.522395E 00	0.833888E 01	0.250582E 01	0.721520E 04	0.524885E 00
0.600000E 02	0.491913E 01	0.848594E 00	0.125083E 02	0.407054E 01	0.927557E 04	0.565227E 00
0.800000E 02	0.713156E 01	0.123025E 01	0.166777E 02	0.590130E 01	0.105423E 05	0.610154E 00
0.100000E 03	0.973435E 01	0.167926E 01	0.208472E 02	0.805509E 01	0.111712E 05	0.659131E 00
0.120000E 03	0.126136E 02	0.221046E 01	0.250166E 02	0.106031E 02	0.112997E 05	0.712332E 00
0.140000E 03	0.164777E 02	0.284256E 01	0.291861E 02	0.136351E 02	0.110470E 05	0.753964E 00
0.160000E 03	0.208639E 02	0.359922E 01	0.333555E 02	0.172647E 02	0.105154E 05	0.777742E 00
0.180000E 03	0.261473E 02	0.451064E 01	0.375250E 02	0.216366E 02	0.979080E 04	0.785435E 00
0.198048E 03	0.318708E 02	0.549800E 01	0.412876E 02	0.263728E 02	0.903039E 04	0.780087E 00

**** BURNOUT AT ABOVE LINE

V	(1+MU)*L	MU*L	MU*V	L	P	H
0.200000E 03	0.325577E 02	0.561650E 01	0.416944E 02	0.269412E 02	0.882536E 04	0.778751E 00
0.210000E 03	0.360000E 02	0.628978E 01	0.437791E 02	0.301708E 02	0.779870E 04	0.766668E 00

GUN

A	BORE AREA (SQ IN)	= 0.785400000E 02
BARL	BARREL LENGTH (IN)	= 0.360000000E 02
BARLP	BARREL LENGTH TO PEAK PRESS (IN)	= 0.12154829E 02
VC	CHAMBER VOLUME (CUBIC IN)	= 0.970000000E 03
X0	CHAMBER LENGTH (IN)	= 0.123503946E 02
XM	BARREL PLUS CHAMBER LENGTH (IN)	= 0.483503946E 02
XB	BARREL + CHAMB LEN TO BURNOUT(IN)	= 0.442212176E 02
LM	PROJECTILE TRAVEL TO MUZZLE (IN)	= 0.301708346E 02
LB	PROJECTILE TRAVEL TO BURNOUT(IN)	= 0.263728216E 02
LR	RECOIL TRAVEL (IN)	= 0.62897809E 01

	MPR	EFFECTIVE RECOIL MASS (SLUG)	= 0.40993788E 03
	WR	RECOIL WEIGHT (LB)	= 0.12000000E 05
PROJECTILE	WO	PROJECTILE WEIGHT (LB)	= 0.25000000E 04
	MP	EFFECTIVE PROJECTILE MASS (SLUG)	= 0.85460662E 02
	FS	PROJECTILE FRICTION + SPIN LOSS	= 0.10000000E 00
	FSR	RECOIL FRICTION + SPIN LOSS	= 0.10000000E 00
CHARGE	C	CHARGE WEIGHT (LB)	= 0.10000000E 02
	WEB	WEB THICKNESS (IN)	= 0.86200000E-01
	BRC	BURN RATE COEF (IN/SEC PSI)	= 0.20000000E-03
	F	IMPETUS (FT LB/LB)	= 0.31700000E 06
	RHO	DENSITY (LB/CUBIC IN)	= 0.57000000E-01
	GAMMA	SPECIFIC HEAT RATIO	= 0.12500000E 01
	GMB	PSEUDO SPECIFIC HEAT RATIO	= 0.13750000E 01
	BETA	HEAT LOSS FACTOR	= 0.50000000E 00
	N	COVOLUME (CUBIC IN/LB)	= 0.27000000E 02
	RP	REGRESSIVENESS	= 0.00000000E 00
OUTPUT	VM	MUZZLE VELOCITY (FT/SEC)	= 0.21000000E 03
	VB	BURNOUT VELOCITY (FT/SEC)	= 0.19804866E 03
	VR	RECOIL VELOCITY (FT/SEC)	= 0.43779166E 02
	PP	PEAK PRESSURE (PSI)	= 0.11308062E 05
	PB	BURNCUT PRESSURE (PSI)	= 0.90303969E 04
	PM	MUZZLE PRESSURE (PSI)	= 0.77987064E 04
	HP	PIEZOMETRIC EFFICIENCY	= 0.76666835E 00
	TM	TIME TO SHOT EJECTION (SEC)	= 0.33131851E-01
	TPP	TIME TO PEAK PRESSURE (SEC)	= 0.23009945E-01
PARAMETERS	MU		= 0.20847222E 00
	E2		= 0.18729280E 03
	U		= 0.22658854E 00
	ZB		= 0.10574280E 00
	AO		= 0.31714909E 01
	A1		= 0.92191599E-01
	A2		= 0.00000000E 00
	ALPHA		= 0.18086455E 00

BARL SPECIFIED. VM NOT SPECIFIED.
WEB SPECIFIED. VB NOT SPECIFIED.
UNCONSTRAINED CHARGE.
ANCHOR BALLISTICS   SAND   PROJECTILE WITH   12 LB M6 CHARGE

V	(1+MU)*L	MU*L	MU*V	L	P	H
0.200000E 02	0.110147E 01	0.190035E 00	0.417000E 01	0.911442E 00	0.541318E 04	0.480864E 00
0.400000E 02	0.233922E 01	0.403581E 00	0.834000E 01	0.193564E 01	0.961552E 04	0.509877E 00
0.600000E 02	0.373570E 01	0.644513E 00	0.125100E 02	0.309119E 01	0.127585E 05	0.541401E 00
0.800000E 02	0.531768E 01	0.917449E 00	0.166800E 02	0.440023E 01	0.149866E 05	0.575629E 00
0.100000E 03	0.711717E 01	0.122791E 01	0.208500E 02	0.588926E 01	0.164356E 05	0.612768E 00
0.120000E 03	0.917262E 01	0.158253E 01	0.250200E 02	0.759008E 01	0.172313E 05	0.653040E 00
0.140000E 03	0.115303E 02	0.198931E 01	0.291899E 02	0.954106E 01	0.174891E 05	0.696684E 00
0.160000E 03	0.142465E 02	0.245792E 01	0.333600E 02	0.117886E 02	0.173130E 05	0.736455E 00
0.180000E 03	0.173894E 02	0.300016E 01	0.375300E 02	0.143892E 02	0.167961E 05	0.763616E 00
0.198022E 03	0.206558E 02	0.356370E 01	0.412876E 02	0.170920E 02	0.161065E 05	0.778040E 00

**** BURNOUT AT ABOVE LINE

V	(1+MU)*L	MU*L	MU*V	L	P	H
0.200000E 03	0.210453E 02	0.363090E 01	0.417000E 02	0.174144E 02	0.158125E 05	0.778969E 00
0.220000E 03	0.256913E 02	0.443247E 01	0.458700E 02	0.212588E 02	0.129130E 05	0.772101E 00
0.240000E 03	0.320276E 02	0.552565E 01	0.500400E 02	0.265019E 02	0.102034E 05	0.737078E 00
0.250000E 03	0.360000E 02	0.622480E 01	0.521250E 02	0.299551E 02	0.894269E 04	0.709953E 00

GUN

A	BORE AREA (SQ IN)	=	0.78540000E 02
BARL	BARREL LENGTH (IN)	=	0.36000000E 02
BARLP	BARREL LENGTH TO PEAK PRESS (IN)	=	0.11784837E 02
VC	CHAMBER VOLUME (CUBIC IN)	=	0.97000000E 03
XO	CHAMBER LENGTH (IN)	=	0.12350394E 02
XM	BARREL PLUS CHAMBER LENGTH (IN)	=	0.48350394E 02

A-9

```
                XB   BARREL + CHAMB LEN TO BURNOUT(IN) =  0.33006195E 02
                LM   PROJECTILE TRAVEL TO MUZZLE (IN)  =  0.29855181E 02
                LB   PROJECTILE TRAVEL TO BURNOUT(IN)  =  0.17092098E 02
                LR   RECOIL TRAVEL (IN)                =  0.62248052E 01
                MPR  EFFECTIVE RECOIL MASS (SLUG)      =  0.40993788E 03
                WR   RECOIL WEIGHT (LB)                =  0.12000000E 05
PROJECTILE      WO   PROJECTILE WEIGHT (LB)            =  0.25000000E 04
                MP   EFFECTIVE PROJECTILE MASS (SLUG)  =  0.85472049E 02
                FS   PROJECTILE FRICTION + SPIN LOSS   =  0.10000000E 0C
                FSR  RECOIL FRICTION + SPIN LOSS       =  0.10000000E 00
CHARGE          C    CHARGE WEIGHT (LB)                =  0.12000000E 02
                WEB  WEB THICKNESS (IN)                =  0.86200000E-01
                BRC  BURN RATE COEF (IN/SEC PSI)       =  0.20000000E-03
                F    IMPETUS (FT LB/LB)                =  0.31700000E 06
                RHO  DENSITY (LB/CUBIC IN)             =  0.57000000E-01
                GAMMA SPECIFIC HEAT RATIO              =  0.12500000E 01
                GMB  PSEUDO SPECIFIC HEAT RATIO        =  0.13750000E 01
                BETA HEAT LOSS FACTOR                  =  0.50000000E 00
                N    COVOLUME (CUBIC IN/LB)            =  0.27000000E 02
                RP   REGRESSIVENESS                    =  0.00000000E 00
OUTPUT          VM   MUZZLE VELOCITY (FT/SEC)          =  0.25000000E 03
                VB   BURNOUT VELOCITY (FT/SEC)         =  0.19802227E 03
                VR   RECOIL VELOCITY (FT/SEC)          =  0.52125000E 02
                PP   PEAK PRESSURE (PSI)               =  0.17489402E 05
                PB   BURNOUT PRESSURE (PSI)            =  0.16106543E 05
                PM   MUZZLE PRESSURE (PSI)             =  0.89426966E 04
                HP   PIEZOMETRIC EFFICIENCY            =  0.70995338E 00
                TM   TIME TO SHOT EJECTION (SEC)       =  0.27280548E-01
                TPP  TIME TO PEAK PRESSURE (SEC)       =  0.18996115E-01
PARAMETERS      MU                                     =  0.20849999E 00
                E2                                     =  0.22475135E 03
                U                                      =  0.22693375E 00
                ZB                                     =  0.88107264E 00
                AO                                     =  0.40056748E 01
                A1                                     =  0.13277359E 00
                A2                                     =  0.00000000E 00
                ALPHA                                  =  0.21703743E 00
```

BARL SPECIFIED. VM NOT SPECIFIED.
WEB SPECIFIED. VB NOT SPECIFIED.
UNCONSTRAINED CHARGE.
ANCHOR BALLISTICS   SAND   PROJECTILE WITH 14 LB M6 CHARGE

V	(1+MU)*L	MU*L	MU*V	L	P	H
0.200000E 02	0.890571E 00	0.153665E 00	0.417055E 01	0.736906E 00	0.676927E 04	0.475608E 00
0.400000E 02	0.186920E 01	0.322525E 00	0.834111E 01	0.154667E 01	0.123004E 05	0.498819E 00
0.600000E 02	0.294814E 01	0.508692E 00	0.125116E 02	0.243944E 01	0.157082E 05	0.523869E 00
0.800000E 02	0.414160E 01	0.714620E 00	0.166822E 02	0.342698E 01	0.201072E 05	0.550884E 00
0.100000E 03	0.546612E 01	0.943163E 00	0.208527E 02	0.452296E 01	0.226098E 05	0.579995E 00
0.120000E 03	0.694104E 01	0.119765E 01	0.250233E 02	0.574338E 01	0.243250E 05	0.611342E 00
0.140000E 03	0.858897E 01	0.148200E 01	0.291938E 02	0.710697E 01	0.253575E 05	0.645072E 00
0.160000E 03	0.104364E 02	0.180078E 01	0.333644E 02	0.863571E 01	0.258059E 05	0.681343E 00
0.180000E 03	0.125149E 02	0.215940E 01	0.375349E 02	0.103554E 02	0.257627E 05	0.718091E 00
0.197995E 03	0.146128E 02	0.252139E 01	0.412876E 02	0.120914E 02	0.253743E 05	0.744115E 00

**** BURNOUT AT ABOVE LINE

V	(1+MU)*L	MU*L	MU*V	L	P	H
0.200000E 03	0.148630E 02	0.256457E 01	0.417055E 02	0.122984E 02	0.249854E 05	0.746472E 00
0.220000E 03	0.177513E 02	0.306293E 01	0.458761E 02	0.145883E 02	0.211479E 05	0.756270E 00
0.240000E 03	0.215363E 02	0.371603E 01	0.500466E 02	0.178203E 02	0.174572E 05	0.741843E 00
0.260000E 03	0.265935E 02	0.458863E 01	0.542172E 02	0.220049E 02	0.140027E 05	0.705070E 00
0.280000E 03	0.335200E 02	0.578378E 01	0.583877E 02	0.277362E 02	0.108612E 05	0.648744E 00
0.286000E 03	0.360000E 02	0.622823E 01	0.595389E 02	0.298676E 02	0.998947E 04	0.628545E 00

GUN   A   BORE AREA (SQ IN)   = 0.785400000E 02
      BARL BARREL LENGTH (IN)   = 0.360000000E 02

BARLP	BARREL LENGTH TO PEAK PRESS (IN)	=	0.11238219E 02
VC	CHAMBER VOLUME (CUBIC IN)	=	0.97000000E 03
XO	CHAMBER LENGTH (IN)	=	0.12350394E 02
XM	BARREL PLUS CHAMBER LENGTH (IN)	=	0.48350394E 02
XB	BARREL + CHAMB LEN TO BURNOUT(IN)	=	0.26963227E 02
LM	PROJECTILE TRAVEL TO MUZZLE (IN)	=	0.29867658E 02
LB	PROJECTILE TRAVEL TO BURNOUT(IN)	=	0.12091433E 02
LR	RECOIL TRAVEL (IN)	=	0.62282363E 01
MPR	EFFECTIVE RECOIL MASS (SLUG)	=	0.40993788E 03
WR	RECOIL WEIGHT (LB)	=	0.12000000E 05
PROJECTILE WO	PROJECTILE WEIGHT (LB)	=	0.25000000E 04
MP	EFFECTIVE PROJECTILE MASS (SLUG)	=	0.85483436E 02
FS	PROJECTILE FRICTION + SPIN LOSS	=	0.10000000E 00
FSR	RECOIL FRICTION + SPIN LOSS	=	0.10000000E 00
CHARGE C	CHARGE WEIGHT (LB)	=	0.14000000E 02
WEB	WEB THICKNESS (IN)	=	0.86200000E-01
BRC	BURN RATE COEF (IN/SEC PSI)	=	0.20000000E-03
F	IMPETUS (FT LB/LB)	=	0.31700000E 06
RHO	DENSITY (LB/CUBIC IN)	=	0.57000000E-01
GAMMA	SPECIFIC HEAT RATIO	=	0.12500000E 01
GMB	PSEUDO SPECIFIC HEAT RATIO	=	0.13750000E 01
BETA	HEAT LOSS FACTOR	=	0.50000000E 00
N	COVOLUME (CUBIC IN/LB)	=	0.27000000E 02
RP	REGRESSIVENESS	=	0.00000000E 00
OUTPUT VM	MUZZLE VELOCITY (FT/SEC)	=	0.28600000E 03
VB	BURNOUT VELOCITY (FT/SEC)	=	0.19799590E 03
VR	RECOIL VELOCITY (FT/SEC)	=	0.59638944E 02
PP	PEAK PRESSURE (PSI)	=	0.25842744E 05
PB	BURNOUT PRESSURE (PSI)	=	0.25374368E 05
PM	MUZZLE PRESSURE (PSI)	=	0.99894777E 04
HP	PIEZOMETRIC EFFICIENCY	=	0.62554554E 00
TM	TIME TO SHOT EJECTION (SEC)	=	0.23129786E-01
TPP	TIME TO PEAK PRESSURE (SEC)	=	0.15904927E-01
PARAMETERS MU		=	0.20852777E 00
E2		=	0.26220992E 03
U		=	0.22659895E 00
ZB		=	0.75510452E 00
AO		=	0.48398208E 01
A1		=	0.18074368E 00
A2		=	0.00000000E 00
ALPHA		=	0.25321034E 00

BARL SPECIFIED. VM NOT SPECIFIED.
WEB SPECIFIED. VB NOT SPECIFIED.
UNCONSTRAINED CHARGE.
ANCHOR BALLISTICS SAND PROJECTILE WITH 16 LB M6 CHARGE

V	(1+MUJ*L	MU*L	MU*V	L	P	H
0.200000E 02	0.7349947E 00	0.126826E 00	0.417111E 01	0.608120E 00	0.827557E 04	0.471406E 00
0.400000E 02	0.152823E 01	0.263721E 00	0.834222E 01	0.126451E 01	0.153137E 05	0.490071E 00
0.600000E 02	0.238687E 01	0.411892E 00	0.125133E 02	0.197497E 01	0.219931E 05	0.510140E 00
0.800000E 02	0.331884E 01	0.572720E 00	0.166844E 02	0.274612E 01	0.259978E 05	0.531699E 00
0.100000E 03	0.433328E 01	0.747776E 00	0.208555E 02	0.358550E 01	0.298143E 05	0.554841E 00
0.120000E 03	0.544058E 01	0.938860E 00	0.250266E 02	0.450172E 01	0.327304E 05	0.579662E 00
0.140000E 03	0.665272E 01	0.114803E 01	0.291977E 02	0.550469E 01	0.348342E 05	0.606263E 00
0.160000E 03	0.798341E 01	0.137766E 01	0.333688E 02	0.660574E 01	0.362125E 05	0.634750E 00
0.180000E 03	0.944846E 01	0.163040?E 01	0.375400E 02	0.781797E 01	0.369504E 05	0.665235E 00
0.197969E 03	0.108943E 02	0.187999E 01	0.412876E 02	0.901434E 01	0.371348E 05	0.694425E 00

**** BURNOUT AT ABOVE LINE

V	(1+MUJ*L	MU*L	MU*V	L	P	H
0.200000E 03	0.110674E 02	0.190986E 01	0.417111E 02	0.915757E 01	0.366424E 05	0.697656E 00
0.220000E 03	0.130126E 02	0.224553E 01	0.456622E 02	0.107670E 02	0.318007E 05	0.717976E 00
0.240000E 03	0.154924E 02	0.267347E 01	0.500533E 02	0.128189E 02	0.270509E 05	0.717681E 00
0.260000E 03	0.186976E 02	0.326657E 01	0.542244E 02	0.154710E 02	0.224973E 05	0.697894E 00
0.280000E 03	0.229145E 02	0.395427E 01	0.583955E 02	0.189603E 02	0.182348E 05	0.660440E 00
0.300000E 03	0.285881E 02	0.493333E 01	0.625666E 02	0.236547E 02	0.143455E 05	0.607696E 00
0.320000E 03	0.364366E 02	0.628772E 01	0.567377E 02	0.301489E 02	0.108956E 05	0.542489E 00
0.320000E 03	0.360000E 02	0.628772E 01	0.667377E 02	0.301489E 02	0.108956E 05	0.542489E 00

GUN

A	BORE AREA (SQ IN)	= 0.78540000E 02
BARL	BARREL LENGTH (IN)	= 0.36000000E 02
BARLP	BARREL LENGTH TO PEAK PRESS (IN)	= 0.10729403E 02
VC	CHAMBER VOLUME (CUBIC IN)	= 0.9700C000E 03
XO	CHAMBER LENGTH (IN)	= 0.12350394E 02
XM	BARREL PLUS CHAMBER LENGTH (IN)	= 0.48350394E 02
XB	BARREL + CHAMB LEN TO BURNOUT(;N)	= 0.23244730E 02
LM	PROJECTILE TRAVEL TO MUZZLE (IN)	= 0.30148917E 02
LB	PROJECTILE TRAVEL TO BURNOUT(IN)	= 0.90143443E 01
LR	RECOIL TRAVEL (IN)	= 0.62877243E 01
MPR	EFFECTIVE RECOIL MASS (SLUG)	= 0.40993788E 03
WR	RECOIL WEIGHT (LB)	= 0.12000000E 05

PROJECTILE

WO	PROJECTILE WEIGHT (LB)	= 0.25000000E 04
MP	EFFECTIVE PROJECTILE MASS (SLUG)	= 0.85494823E 02
FS	PROJECTILE FRICTION + SPIN LOSS	= 0.10000000E 00
FSR	RECOIL FRICTION + SPIN LOSS	= 0.10000000E 00

CHARGE

C	CHARGE WEIGHT (LB)	= 0.16000000E 02
WEB	WEB THICKNESS (IN)	= 0.86200000E-01
BRC	BURN RATE COEF (IN/SEC PSI)	= 0.20000000E-03
F	IMPETUS (FT LB/LB)	= 0.31700000E 06
RHO	DENSITY (LB/CUBIC IN)	= 0.57000000E-01
GAMMA	SPECIFIC HEAT RATIO	= 0.12560000E 01
GME	PSEUDO SPECIFIC HEAT RATIO	= 0.13750000E 01
BETA	HEAT LOSS FACTOR	= 0.50000000E 00
N	COVOLUME (CUBIC IN/LB)	= 0.27000000E 02
RP	REGRESSIVENESS	= 0.00000000E 00

OUTPUT

VM	MUZZLE VELOCITY (FT/SEC)	= 0.32000000E 03
VB	BURNOUT VELOCITY (FT/SEC)	= 0.19796952E 03
VR	RECOIL VELOCITY (FT/SEC)	= 0.66737777E 02
PP	PEAK PRESSURE (PSI)	= 0.37134814E 05
PB	BURNOUT PRESSURE (PSI)	= 0.37134802E 05
PM	MUZZLE PRESSURE (PSI)	= 0.10895619E 05
HP	PIEZOMETRIC EFFICIENCY	= 0.54248965E 00
TM	TIME TO SHOT EJECTION (SEC)	= 0.20045236E-01
TPP	TIME TO PEAK PRESSURE (SEC)	= 0.13498114E-01

PARAMETERS

MU	= 0.20855555E 00
E2	= 0.29966848E 03
U	= 0.22660416E 00
ZB	= 0.66067845E 00
AO	= 0.56739291E 01
A1	= 0.23610483E 00
A2	= 0.00000000E 00
ALPHA	= 0.28938325E 00

BARL SPECIFIED. VM NOT SPECIFIED.
WEB SPECIFIED. VB NOT SPECIFIED.
UNCONSTRAINED CHARGE.

ANCHOR BALLISTICS   MUD   PROJECTILE WITH   2   LB M2 CHARGE

V	(1+MU)*L	MU*L	MU*V	L	P	H
0.200000E 02	0.550866E 01	0.129293E 01	0.613388E 01	0.421572E 01	0.147145E 04	0.562979E 00
0.400000E 02	0.141971E 02	0.333221E 01	0.122677E 02	0.108649E 02	0.183869E 04	0.699255E 00
0.600000E 02	0.283639E 02	0.665731E 01	0.184016E 02	0.217066E 02	0.166390E 04	0.787503E 00
0.800000E 02	0.523512E 02	0.122873E 02	0.245355E 02	0.400638E 02	0.128597E 04	0.758525E 00
0.835527E 02	0.581895E 02	0.136576E 02	0.256251E 02	0.445318E 02	0.121343E 04	0.744378E 00

**** BURNOUT AT ABOVE LINE
**** MUZZLE CONDITIONS HAVE BEEN SATISFIED

GUN
A	BORE AREA (SQ IN)	=	0.7854000000E 02
BARL	BARREL LENGTH (IN)	=	0.3600000000E 02
BARLP	BARREL LENGTH TO PEAK PRESS (IN)	=	0.1419715000E 02
VC	CHAMBER VOLUME (CUBIC IN)	=	0.9700000000E 03
XO	CHAMBER LENGTH (IN)	=	0.1235039400E 02
XM	BARREL PLUS CHAMBER LENGTH (IN)	=	0.4835039400E 02
XB	BARREL + CHAMB LEN TO BURNOUT(IN)	=	0.7053995300E 02
LM	PROJECTILE TRAVEL TO MUZZLE (IN)	=	0.4453187900E 02
LB	PROJECTILE TRAVEL TO BURNOUT(IN)	=	0.4453187900E 02
LR	RECOIL TRAVEL (IN)	=	0.1365767900E 02
MPR	EFFECTIVE RECOIL MASS (SLUG)	=	0.4099378800E 03
WR	RECOIL WEIGHT (LB)	=	0.1200000000E 05

PROJECTILE
WO	PROJECTILE WEIGHT (LB)	=	0.3680000000E 04
MP	EFFECTIVE PROJECTILE MASS (SLUG)	=	0.1257256700E 03
FS	PROJECTILE FRICTION + SPIN LOSS	=	0.1000000000E 00
FSR	RECOIL FRICTION + SPIN LOSS	=	0.1000000000E 00

CHARGE
C	CHARGE WEIGHT (LB)	=	0.2000000000E 01
WEB	WEB THICKNESS (IN)	=	0.1070000000E 00
BRC	BURN RATE COEF (IN/SEC PSI)	=	0.4000000000E-03
F	IMPETUS (FT LB/LB)	=	0.3720000000E 06
RHO	DENSITY (LB/CUBIC IN)	=	0.5900000000E-01
GAMMA	SPECIFIC HEAT RATIO	=	0.1220000000E 01
GMB	PSEUDO SPECIFIC HEAT RATIO	=	0.1330000000E 01

A-15

OUTPUT

BETA	HEAT LOSS FACTOR	= 0.50000000E 00
N	COVOLUME (CUBIC IN/LB)	= 0.27000000E 02
RP	REGRESSIVENESS	= 0.00000000E 00
VM	MUZZLE VELOCITY (FT/SEC)	= 0.25498274E-02
VB	BURNOUT VELOCITY (FT/SEC)	= 0.83552744E 02
VR	RECOIL VELOCITY (FT/SEC)	= 0.25625162E 02
PP	PEAK PRESSURE (PSI)	= 0.18386922E 04
PB	BURNOUT PRESSURE (PSI)	= 0.12134373E 04
PM	MUZZLE PRESSURE (PSI)	= 0.12134373E 04
HP	PIEZOMETRIC EFFICIENCY	= 0.19730530E-09
TM	TIME TO SHOT EJECTION (SEC)	= 0.10095172E 00
TPP	TIME TO PEAK PRESSURE (SEC)	= 0.56664233E-01

PARAMETERS

MU	= 0.30669444E 00
E2	= 0.70825271E 02
U	= 0.21560458E 00
ZB	= 0.11797024E 01
AO	= 0.29313364E 01
A1	= 0.17566630E-01
A2	= 0.00000000E 00
ALPHA	= 0.34946706E-01

ANCHOR BALLISTICS   MUD PROJECTILE WITH 4 LB M2 CHARGE

V	(1+MU)*L	MU*L	MU*V	L	P	H
0.200000E 02	0.235485E 01	0.552745E 00	0.613444E 01	0.180210E 01	0.384624E 04	0.503842E 00
0.400000E 02	0.526850E 01	0.123665E 01	0.122688E 02	0.403184E 02	0.619138E 04	0.559603E 00
0.600000E 02	0.890509E 01	0.209026E 01	0.184033E 02	0.681483E 02	0.740910E 04	0.622492E 00
0.800000E 02	0.134849E 02	0.316528E 01	0.245377E 02	0.103197E 02	0.780950E 04	0.693332E 00
0.835451E 02	0.144163E 02	0.338390E 01	0.256251E 02	0.110324E 02	0.781508E 04	0.706787E 00

**** BURNOUT AT ABOVE LINE

V	(1+MU)*L	MU*L	MU*V	L	P	H
0.100000E 03	0.199564E 02	0.468430E 02	0.306722E 02	0.152721E 02	0.601084E 04	0.731507E 00
0.120000E 03	0.313113E 02	0.734960E 02	0.380066E 02	0.239617E 02	0.396572E 04	0.671370E 00
0.126000E 03	0.360000E 03	0.853216E 02	0.386469E 02	0.278172E 02	0.341433E 04	0.637595E 00

GUN
A	BORE AREA (SQ IN)	= 0.785400000E 02
BARL	BARREL LENGTH (IN)	= 0.360000000E 02
BARLP	BARREL LENGTH TO PEAK PRESS (IN)	= 0.144163640E 02
VC	CHAMBER VOLUME (CUBIC IN)	= 0.970000000E 03
XO	CHAMBER LENGTH (IN)	= 0.123503940E 02
XM	BARREL PLUS CHAMBER LENGTH (IN)	= 0.483503940E 02
XB	BARREL + CHAMB LEN TO BURNOUT(IN)=	0.267667590E 02
LM	PROJECTILE TRAVEL TO MUZZLE (IN)	= 0.278172360E 02
LB	PROJECTILE TRAVEL TO BURNOUT(IN)	= 0.110324630E 02
LR	RECOIL TRAVEL (IN)	= 0.853216440E 01
MPR	EFFECTIVE RECOIL MASS (SLUG)	= 0.409937880E 03
WR	RECOIL WEIGHT (LB)	= 0.120000000E 05

PROJECTILE
WO	PROJECTILE WEIGHT (LB)	= 0.368000000E 04
MP	EFFECTIVE PROJECTILE MASS (SLUG)	= 0.125737050E 03
FS	PROJECTILE FRICTION + SPIN LOSS	= 0.100000000E 05
FSR	RECOIL FRICTION + SPIN LOSS	= 0.100000000E 00

CHARGE
C	CHARGE WEIGHT (LB)	= 0.400000000E 01
WEB	WEB THICKNESS (IN)	= 0.107000000E 00

```
BRC       BURN RATE COEF (IN/SEC PSI)        =  0.40000000E-03
F         IMPETUS (FT LB/LB)                 =  0.37200000E 06
RHO       DENSITY (LB/CUBIC IN)              =  0.59000000E-01
GAMMA     SPECIFIC HEAT RATIO                =  0.12200000E 01
GMB       PSEUDO SPECIFIC HEAT RATIO         =  0.13300000E 01
BETA      HEAT LOSS FACTOR                   =  0.50000000E 00
N         COVOLUME (CUBIC IN/LB)             =  0.27000000E 02
RP        REGRESSIVENESS                     =  0.00000000E 00

OUTPUT    VM   MUZZLE VELOCITY (FT/SEC)      =  0.12600000E 03
          VB   BURNOUT VELOCITY (FT/SEC)     =  0.83545177E 02
          VR   RECOIL VELOCITY (FT/SEC)      =  0.38646995E 02
          PP   PEAK PRESSURE (PSI)           =  0.78150870E 04
          PB   BURNOUT PRESSURE (PSI)        =  0.78150878E 04
          PM   MUZZLE PRESSURE (PSI)         =  0.34143359E 04
          HP   PIEZOMETRIC EFFICIENCY        =  0.63759594E 00
          TM   TIME TO SHOT EJECTION (SEC)   =  0.45566559E-01
          TPP  TIME TO PEAK PRESSURE (SEC)   =  0.32577769E-01

PARAMETERS MU                                =  0.30672222E 00
          E2                                 =  0.14165054E 03
          U                                  =  0.21560916E 00
          ZB                                 =  0.58979779E 00
          AO                                 =  0.68525059E 01
          A1                                 =  0.70272886E-01
          A2                                 =  0.00000000E 00
          ALPHA                              =  0.69893412E-01
```

A-18

BARL SPECIFIED. VM NOT SPECIFIED.
WEB SPECIFIED. VB NOT SPECIFIED.
UNCONSTRAINED CHARGE.
ANCHOR BALLISTICS   MUD PROJECTILE WITH 6 LB M2 CHARGE

V	(1+MU)*L	MU*L	MU*V	L	P	H
0.200000E 02	0.145090E 01	0.340590E 00	0.613499E 01	0.110031E 01	0.649117E 04	0.484553E 00
0.400000E 02	0.310556E 01	0.729007E 00	0.122699E 02	0.237655E 01	0.113577E 05	0.517526E 00
0.600000E 02	0.500143E 01	0.117404E 01	0.184049E 02	0.382738E 01	0.148349E 05	0.553563E 00
0.800000E 02	0.718392E 01	0.168637E 01	0.245399E 02	0.549755E 01	0.171427E 05	0.592901E 00
0.835376E 02	0.760379E 01	0.178493E 01	0.256251E 02	0.581885E 01	0.174448E 05	0.600222E 00

**** BURNOUT AT ABOVE LINE

V	(1+MU)*L	MU*L	MU*V	L	P	H
0.100000E 03	0.996700E 01	0.233968E 01	0.306749E 02	0.762732E 01	0.147913E 05	0.656166E 00
0.120000E 03	0.142117E 02	0.333610E 01	0.368099E 02	0.108756E 02	0.114844E 05	0.662663E 00
0.140000E 03	0.209018E 02	0.490656E 01	0.429449E 02	0.159953E 02	0.833017E 04	0.613266E 00
0.160000E 03	0.320165E 02	0.751565E 01	0.490799E 02	0.245008E 02	0.555388E 04	0.522930E 00
0.165999E 03	0.360000E 02	0.863031E 01	0.509204E 02	0.281346E 02	0.482114E 04	0.490185E 00

GUN

A	BORE AREA (SQ IN)	=	0.78540000E 02
BARL	BARREL LENGTH (IN)	=	0.36000000E 02
BARLP	BARREL LENGTH TO PEAK PRESS (IN)	=	0.76037939E 01
VC	CHAMBER VOLUME (CUBIC IN)	=	0.97000000E 03
XO	CHAMBER LENGTH (IN)	=	0.12350394E 02
XH	BARREL PLUS CHAMBER LENGTH (IN)	=	0.48250394E 02
XB	BARREL + CHAMB LEN TO BURNOUT(IN)	=	0.19954138E 02
LM	PROJECTILE TRAVEL TO MUZZLE (IN)	=	0.28134679E 02
LB	PROJECTILE TRAVEL TO BURNOUT(IN)	=	0.58188589E 01
LR	RECOIL TRAVEL (IN)	=	0.86303129E 01
MPR	EFFECTIVE RECOIL MASS (SLUG)	=	0.40993788E 03
WR	RECOIL WEIGHT (LB)	=	0.12000000E 05
PROJECTILE WO	PROJECTILE WEIGHT (LB)	=	0.36800000E 04
MP	EFFECTIVE PROJECTILE MASS (SLUG)	=	0.12574844E 03

CHARGE	FS	PROJECTILE FRICTION + SPIN LOSS	=	0.10000000E 00
	FSR	RECOIL FRICTION + SPIN LOSS	=	0.10000000E 00
	C	CHARGE WEIGHT (LB)	=	0.60000000E 01
	WEB	WEB THICKNESS (IN)	=	0.10700000E 00
	BRC	BURN RATE COEF (IN/SEC PSI)	=	0.40000000E-03
	F	IMPETUS (FT LB/LB)	=	0.37200000E 06
	RHO	DENSITY (LB/CUBIC IN)	=	0.59000000E-01
	GAMMA	SPECIFIC HEAT RATIO	=	0.12200000E 01
	GMB	PSEUDO SPECIFIC HEAT RATIO	=	0.13300000E 01
	BETA	HEAT LOSS FACTOR	=	0.50000000E 00
	N	COVOLUME (CUBIC IN/LB)	=	0.27000000E 02
	RP	REGRESSIVENESS	=	0.00000000E 00
OUTPUT	VM	MUZZLE VELOCITY (FT/SEC)	=	0.16599999E 03
	VB	BURNOUT VELOCITY (FT/SEC)	=	0.83537612E 02
	VR	RECOIL VELOCITY (FT/SEC)	=	0.50920499E 02
	PP	PEAK PRESSURE (PSI)	=	0.17444812E 05
	PB	BURNOUT PRESSURE (PSI)	=	0.48211423E 05
	PM	MUZZLE PRESSURE (PSI)	=	0.49018520E 04
	HP	PIEZOMETRIC EFFICIENCY	=	0.32655528E-01
	TM	TIME TO SHOT EJECTION (SEC)	=	0.18735421E-01
	TPP	TIME TO PEAK PRESSURE (SEC)	=	0.30674999E 00
PARAMETERS	MU		=	0.21247581E 03
	E2		=	0.21561374E 00
	U		=	0.39316292E 00
	ZB		=	0.10793508E 02
	A0		=	0.15812831E 00
	A1		=	0.00000000E 00
	A2		=	0.10484911E 00
	ALPHA		=	

A-20

BARL SPECIFIED. VM NOT SPECIFIED.
WEB SPECIFIED. VB NOT SPECIFIED.
UNCONSTRAINED CHARGE.

ANCHOR BALLISTICS   MUD   PROJECTILE WITH   8   LB M2 CHARGE

V	(1+MU)*L	MU*L	MU*V	L	P	H
0.200000E 02	0.102321E 01	0.240208E 00	0.613555E 01	0.783004E 00	0.940298E 04	0.474331E 00
0.400000E 02	0.214017E 01	0.502424E 00	0.122711E 02	0.163774E 01	0.172001E 05	0.495899E 00
0.600000E 02	0.336342E 01	0.789594E 00	0.184066E 02	0.257383E 01	0.235207E 05	0.519187E 00
0.800000E 02	0.470744E 01	0.110511E 01	0.245422E 02	0.360232E 01	0.284976E 05	0.544302E 00
0.835300E 02	0.495842E 01	0.116403E 01	0.256251E 02	0.379438E 01	0.292466E 05	0.548933E 00

**** BURNOUT AT ABOVE LINE

V	(1+MU)*L	MU*L	MU*V	L	P	H
0.100000E 03	0.633738E 01	0.148775E 01	0.306777E 02	0.484962E 01	0.259301E 05	0.615556E 00
0.120000E 03	0.867303E 01	0.203607E 01	0.368133E 02	0.663695E 01	0.216178E 05	0.647693E 00
0.140000E 03	0.120592E 02	0.283102E 01	0.429488E 02	0.922824E 01	0.172430E 05	0.634034E 00
0.160000E 03	0.170885E 02	0.401168E 01	0.490844E 02	0.130768E 02	0.130620E 05	0.584404E 00
0.180000E 03	0.248561E 02	0.583519E 01	0.552199E 02	0.190209E 02	0.929948E 04	0.508498E 00
0.200000E 03	0.375460E 02	0.881426E 01	0.613555E 02	0.287317E 02	0.612832E 04	0.415598E 00
0.200000E 03	0.360000E 02	0.881426E 01	0.613555E 02	0.287317E 02	0.612832E 04	0.415598E 00

```
GUN    A      BORE AREA (SQ IN)                      =  0.785400000E 02
       BARL   BARREL LENGTH (IN)                     =  0.360000000E 02
       BARLP  BARREL LENGTH TO PEAK PRESS (IN)       =  0.495842207E 01
       VC     CHAMBER VOLUME (CUBIC IN)              =  0.970000000E 03
       XQ     CHAMBER LENGTH (IN)                    =  0.123503946E 02
       XM     BARREL PLUS CHAMBER LENGTH (IN)        =  0.483503946E 02
       XB     BARREL + CHAMB LEN TO BURNOUT(IN)=     0.173088815E 02
       LM     PROJECTILE TRAVEL TO MUZZLE (IN)    =  0.287317586E 02
       LB     PROJECTILE TRAVEL TO BURNOUT(IN)    =  0.379438700E 01
       LR     RECOIL TRAVEL (IN)                  =  0.881426510E 01
```

			Value
PROJECTILE	MPR	EFFECTIVE RECOIL MASS (SLUG)	0.40993788E 03
	WR	RECOIL WEIGHT (LB)	0.12000000E 05
	WO	PROJECTILE WEIGHT (LB)	0.36800000E 04
	MP	EFFECTIVE PROJECTILE MASS (SLUG)	0.12575983E 03
	FS	PROJECTILE FRICTION + SPIN LOSS	0.10000000E 00
	FSR	RECOIL FRICTION + SPIN LOSS	0.10000000E 00
CHARGE	C	CHARGE WEIGHT (LB)	0.80000000E 01
	WEB	WEB THICKNESS (IN)	0.10700000E 00
	BRC	BURN RATE COEF (IN/SEC PSI)	0.40000000E-03
	F	IMPETUS (FT LB/LB)	0.37200000E 06
	RHO	DENSITY (LB/CUBIC IN)	0.59000000E-01
	GAMMA	SPECIFIC HEAT RATIO	0.12200000E 01
	GMB	PSEUDO SPECIFIC HEAT RATIO	0.13300000E 01
	BETA	HEAT LOSS FACTOR	0.50000000E 00
	N	COVOLUME (CUBIC IN/LB)	0.27000000E 02
	RP	REGRESSIVENESS	0.00000000E 00
OUTPUT	VM	MUZZLE VELOCITY (FT/SEC)	0.20000000E 03
	VB	BURNOUT VELOCITY (FT/SEC)	0.83530048E 02
	VR	RECOIL VELOCITY (FT/SEC)	0.61355555E 02
	PP	PEAK PRESSURE (PSI)	0.29246665E 05
	PB	BURNOUT PRESSURE (PSI)	0.29246655E 05
	PM	MUZZLE PRESSURE (PSI)	0.61283275E 04
	HP	PIEZOMETRIC EFFICIENCY	0.41559826E 00
	TM	TIME TO SHOT EJECTION (SEC)	0.26029077E-01
	TPP	TIME TO PEAK PRESSURE (SEC)	0.12786002E-01
PARAMETERS	MU		0.30677777E 00
	E2		0.28330108E 03
	U		0.21561833E 00
	ZB		0.29484549E 00
	AO		0.14724344E 02
	A1		0.28114246E 00
	A2		0.00000000E 00
	ALPHA		0.13978682E 00
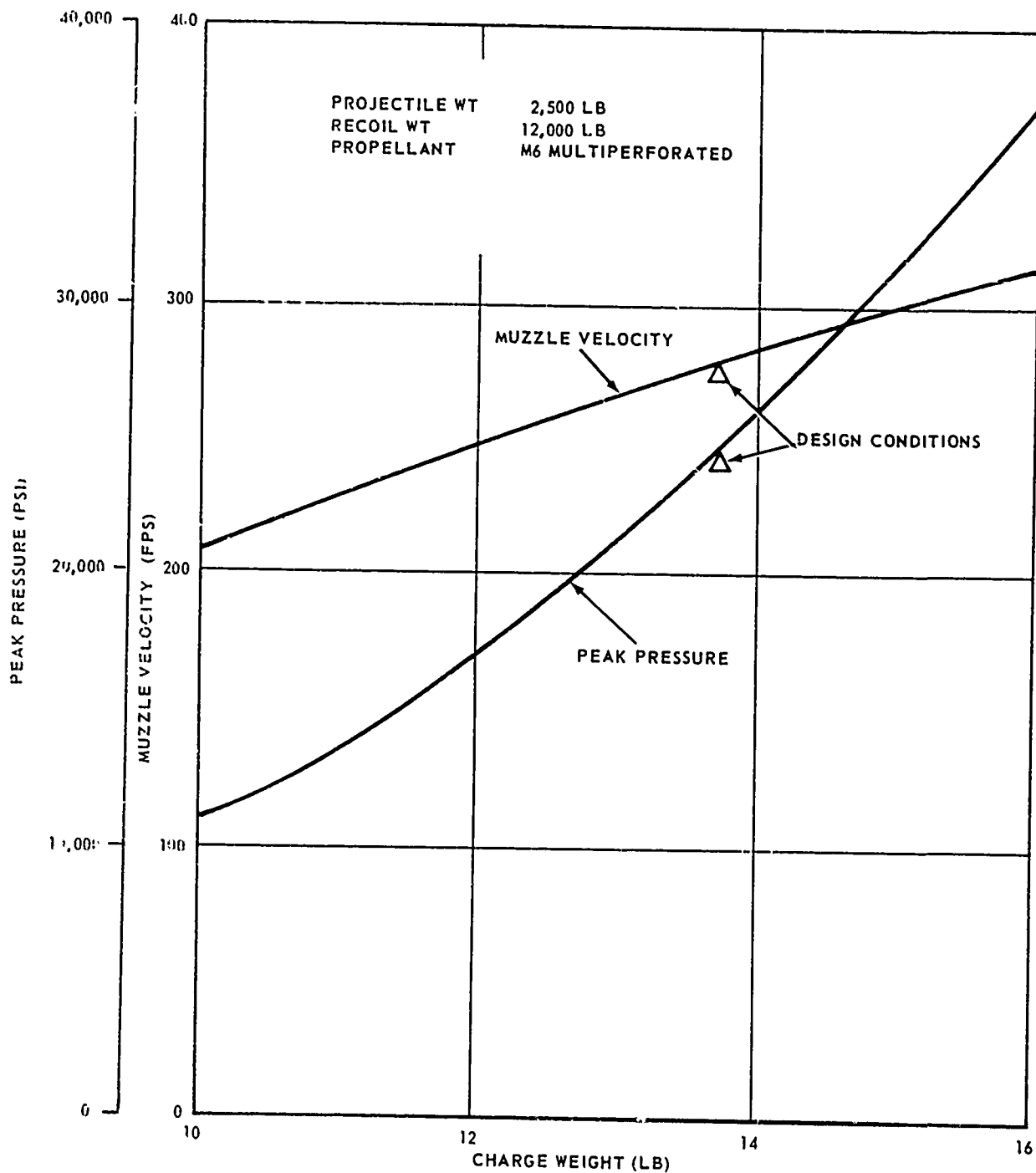
Figure A-1. Anchor Ballistics -- Sand Projectile.

A-23

PROJECTILE WT   3,680 LB
RECOIL WT   12,000
PROPELLANT   M2 MULTIPERFORATED

MUZZLE VELOCITY

DESIGN CONDITIONS

PEAK
PRESSURE

PEAK PRESSURE (PSI)

MUZZLE VELOCITY (FPS)

CHARGE WEIGHT (LB)
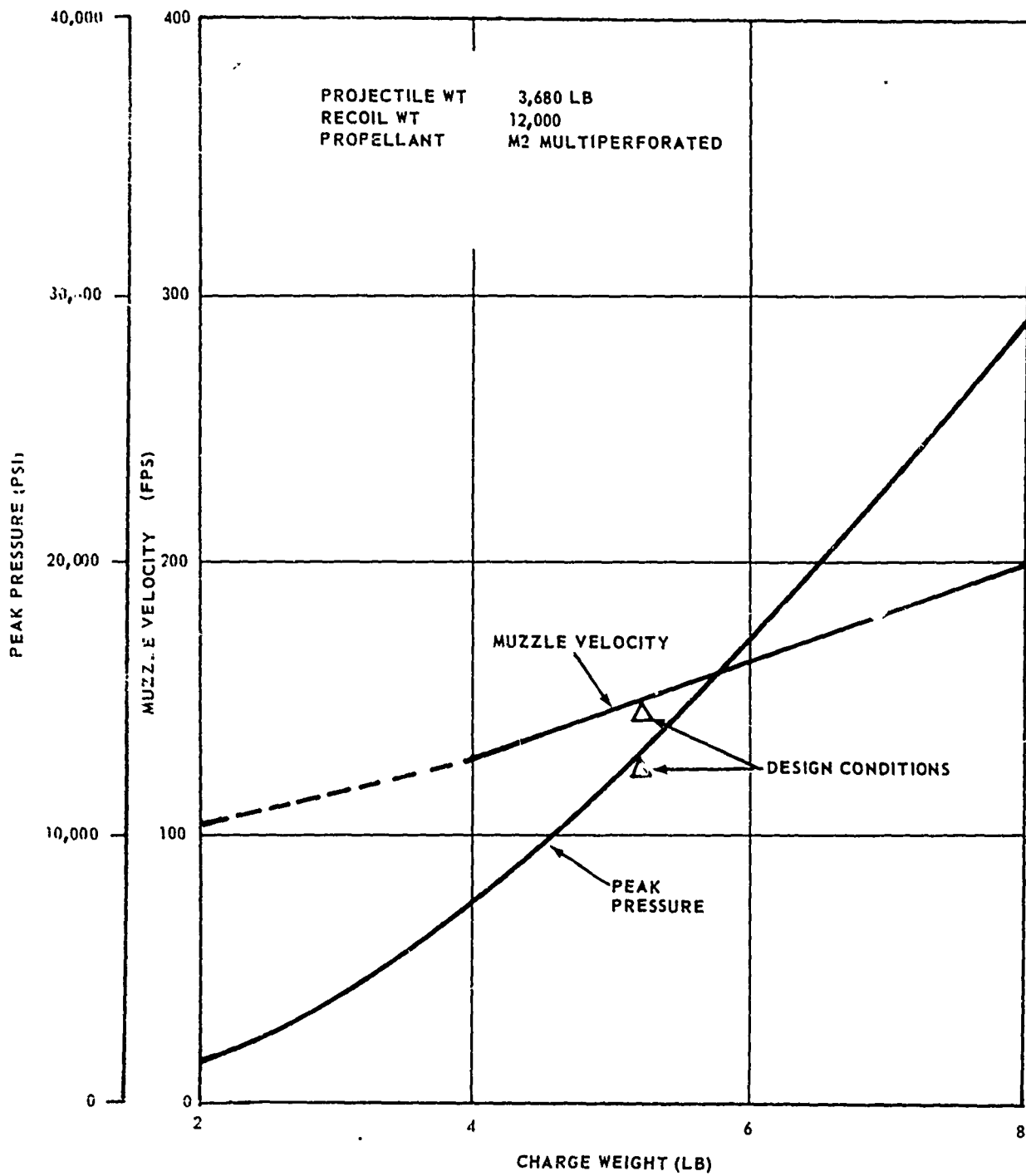
Figure A-2.   Anchor Ballistics -- Mud Projectile

A-24
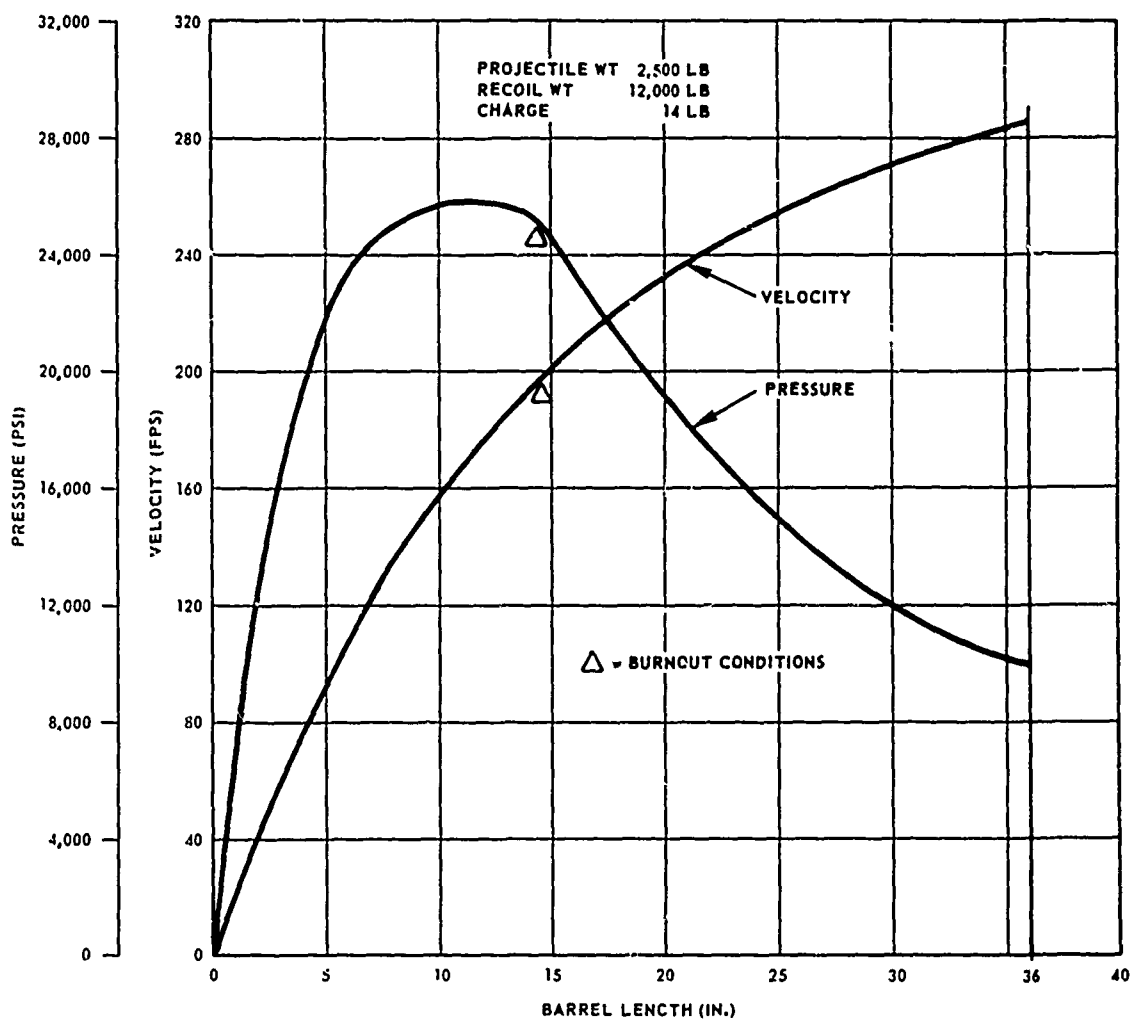
Figure A-3.   Anchor Ballistics -- Sand Projectile.

A-25
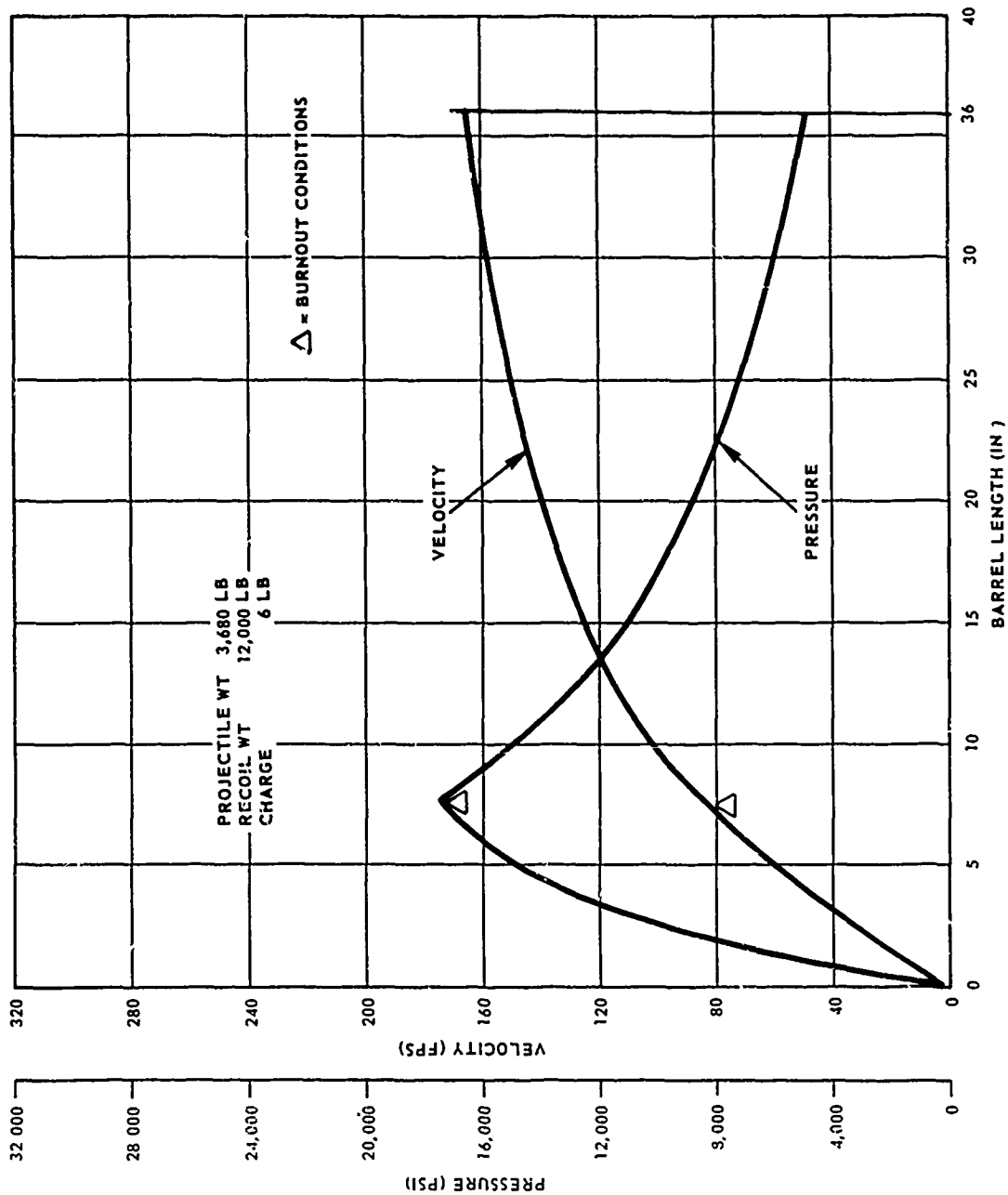
Figure A-4. Anchor Ballistics -- Mud Projectile.

A-26
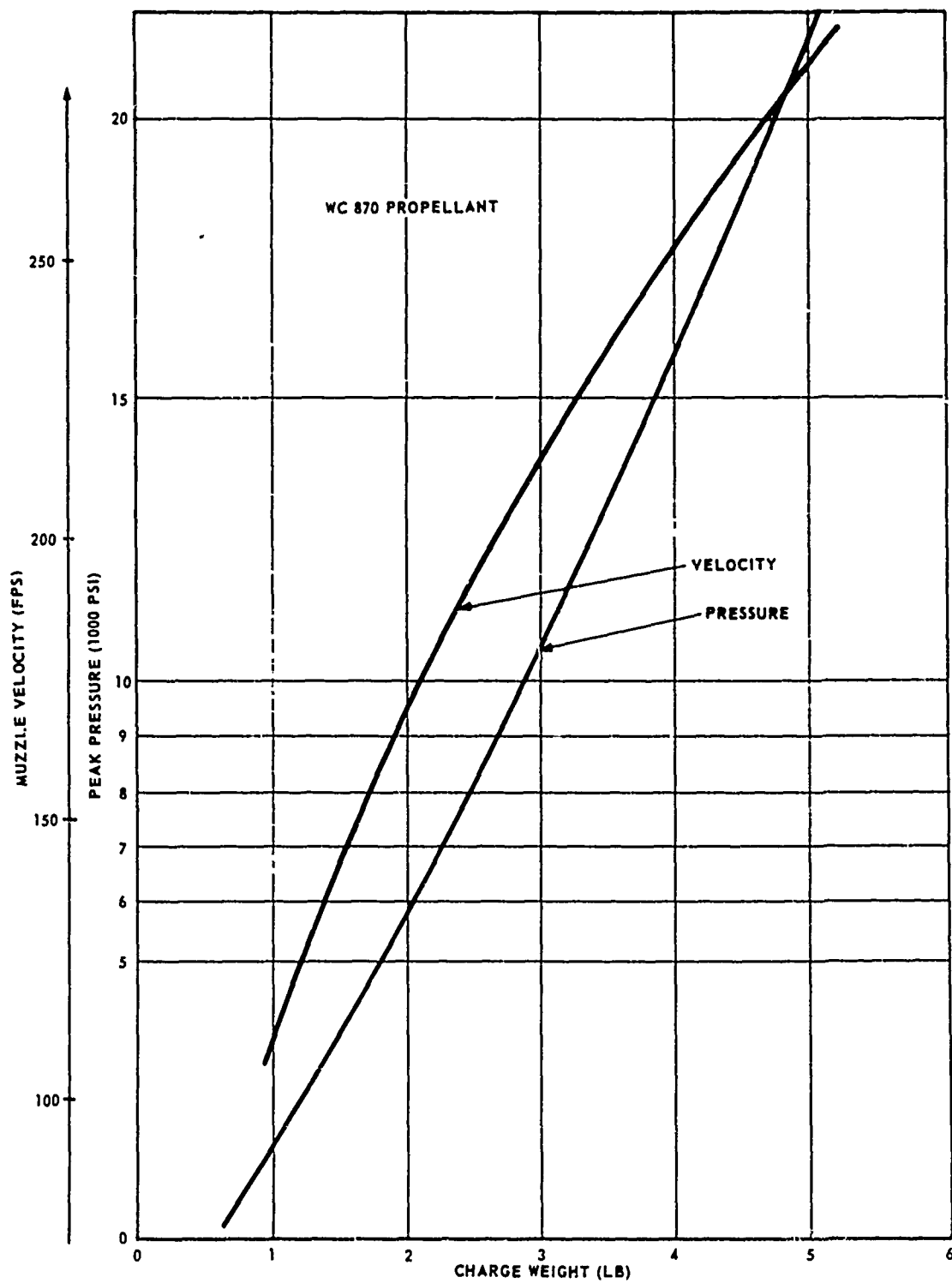
Figure A-5. Anchor Ballistics -- Coral Projectile.

A-27
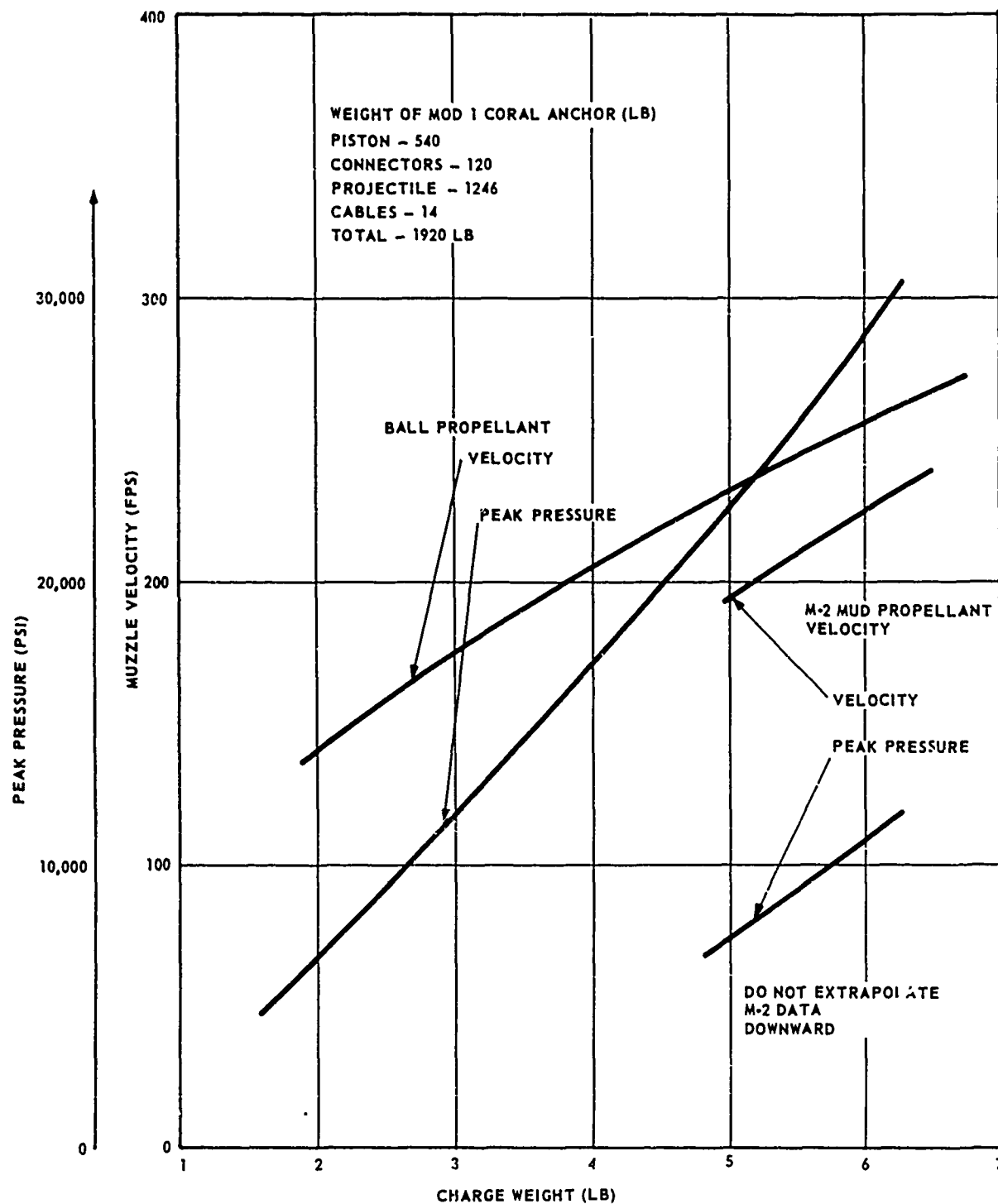
Figure A-6.   Anchor Ballistics -- Coral Projectile.

ALL DIMENSIONS ARE IN INCHES
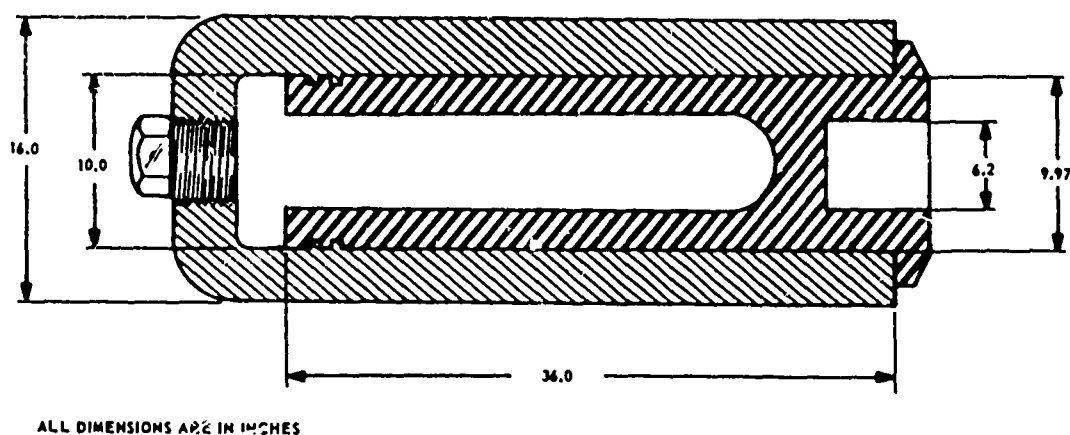
Figure A-7. Barrel and Piston Schematic

For a thick-walled cylinder with internal pressure, maximum circumferential stress occurs at the inner surface. The required outside-diameter-to-inside-diameter ratio can be calculated from

$$\frac{D_o}{D_i} = \sqrt{\frac{3\sigma + 2 P_p (1 + \epsilon)}{3\sigma - 4 P_p (1 + \epsilon)}} \qquad (25)$$

where

D_o = outside diameter (OD)

D_i = inside diameter (ID)

σ = allowable working stress

P_p = peak pressure

$1 + \epsilon$ = safety factor

A-29

$$\frac{D_o}{D_i} = \sqrt{\frac{3 \times 130,000 + 2 \times 30,000 \times 1.667}{3 \times 130,000 + 4 \times 30,000 \times 1.667}} = \sqrt{\frac{490}{190}} = 1.607 \quad (26)$$

$$\therefore \quad \text{barrel OD} = 10 \times 1.6 = 16.0 \text{ in.}$$

$$\text{and} \quad \text{piston ID} = \frac{10}{1.6} = 6.25 \text{ in.}$$

The barrel actual OD is 16.00 ± 0.03 in., and the piston actual ID is 6.20 + 0.02 in. The barrel and piston are both fabricated from 4140 alloy steel heat treated from Rockwell C-34 to C-38, or 150,000 to 170,000 psi tensile strength. An allowable working stress of only 130,000 psi was used in the calculations.

Equation 26, for barrel wall thickness, is from T. H. Hayes, Elements of Ordnance. It is based on allowable strain and gives somewhat conservative results compared to other thick-walled cylinder calculations.

Piston deformation resulting from internal pressure must also be calculated to ensure adequate clearance between the piston OD and barrel ID. The maximum deformation of the piston OD is given by

$$\Delta D_o \bigg|_{max} = P_p (1 + \epsilon) \frac{D_o}{E} \left(\frac{2 D_i^2}{D_o^2 - D_i^2} \right) \quad (27)$$

where

ΔD_o = deformation of piston OD

P_p = peak pressure

$1 + \epsilon$ = safety factor

D_o = piston OD

D_i = piston ID

E = modulus of elasticity

$$\Delta D_o = \frac{30,000 \times 1.667 \times 10}{30 \times 10^6} \left(\frac{2 \times 6.2^2}{10^2 - 6.2^2} \right) \qquad (28)$$

$$\Delta D_o = 0.028 \text{ in.}$$

The actual piston OD and barrel ID of 9.970 -0.005 in. and 10.000 + 0.005 in., respectively, give a minimum clearance of 0.030 in.

Equation 27 is from R.J. Roark, Formulas for Stress and Strain, with a factor of safety on peak pressure included. The factor of safety in this calculation and in the barrel and piston wall thickness calculations was selected to allow a maximum peak pressure of 50,000 psi without failure of the piston or barrel.

Appendix B

TEST PROCEDURE

SIMULATED SYSTEM CHECK-OUT

AEROJET-GENERAL CORPORATION

Engineering Division

Downey, California

W.O.R. 3324-01-160   23 January 1968

TEST PROCEDURE

SIMULATED SYSTEM CHECK-OUT

1. SCOPE

   The objective of this test is to demonstrate system interfaces, sealing capabilities, junction propagation, explosive lead propagation and explosive bolt functioning under water.

2. APPLICABLE DOCUMENTS

   2.1 Aerojet-General Drawings

1215420	Pigtail Assembly
1215404	Explosive Lead Assembly
1215408	Junction Block
1215440	Explosive Bolt Assembly

3. TEST REQUIREMENTS

   3.1 **Test Specimen** - The test specimen shall consist of one (1) 1215420 Pigtail Assembly, two (2) 1215404 Explosive Lead Assembly (24" lg), one (1) 1215408 Junction Block, and two (2) 1215440 Explosive Bolt Assembly plus necessary clamps and steel blocks simulating the reaction vessel and cable connecting lug; all mounted on a backboard as shown in Figure B-1, Test Setup. .

   3.2 **Instrumentation** - None.

   3.3 **Environment** - The entire mounting board except for the electric initiator at the end of the pigtail shall be submerged in water during test.
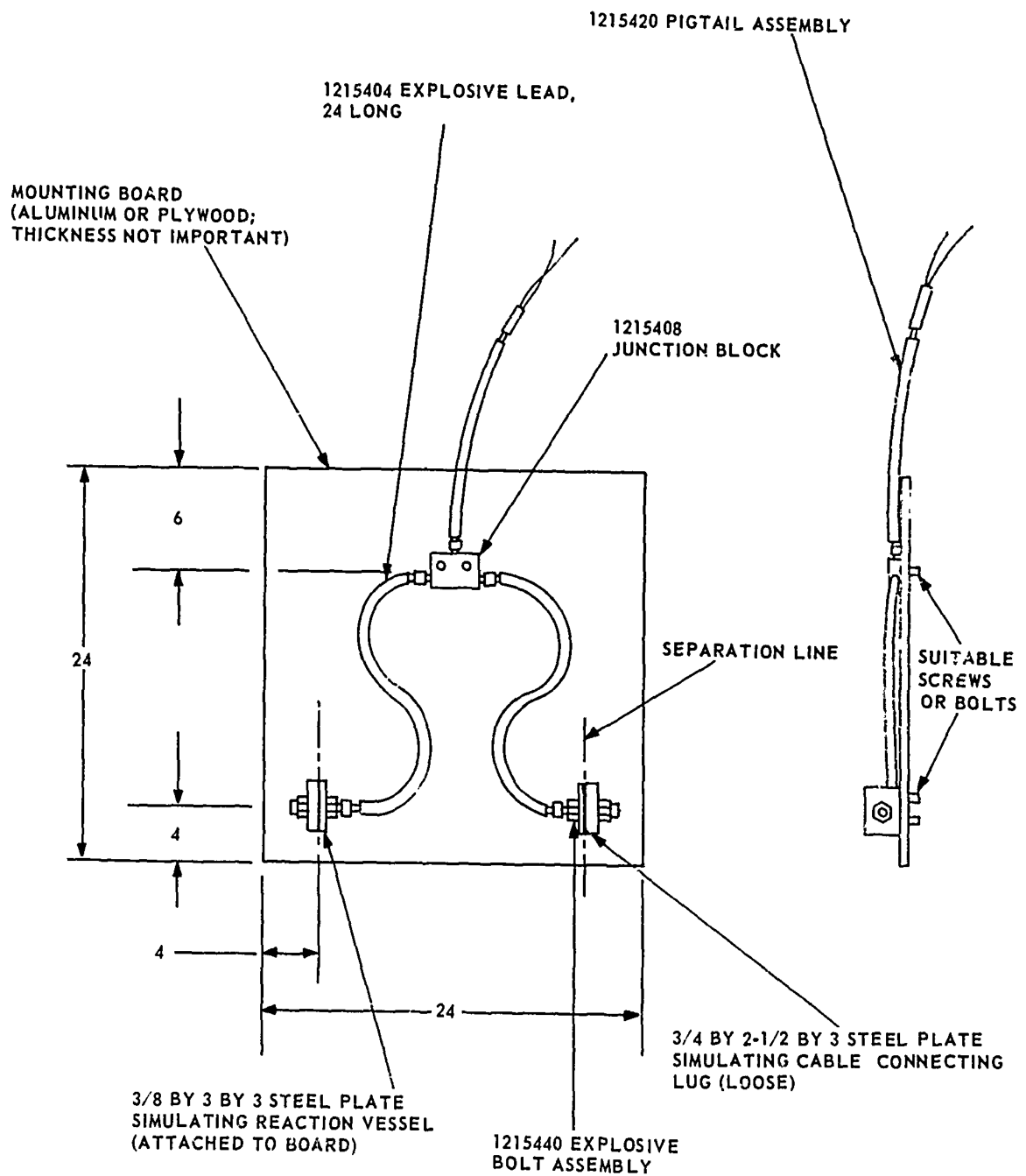
Figure B-1. Test Setup.

The figure includes the following labels:

1215420 PIGTAIL ASSEMBLY

1215404 EXPLOSIVE LEAD, 24 LONG

MOUNTING BOARD (ALUMINUM OR PLYWOOD; THICKNESS NOT IMPORTANT)

1215408 JUNCTION BLOCK

SEPARATION LINE

SUITABLE SCREWS OR BOLTS

3/4 BY 2-1/2 BY 3 STEEL PLATE SIMULATING CABLE CONNECTING LUG (LOOSE)

3/8 BY 3 BY 3 STEEL PLATE SIMULATING REACTION VESSEL (ATTACHED TO BOARD)

1215440 EXPLOSIVE BOLT ASSEMBLY

Dimensions: 6, 24, 4, 4, 24

4. PROCEDURE

   4.1 General – Assemble the components as shown in Figure B-1.
   Torque nut on explosive bolts to 150 ft. lbs.   Submerge in
   water (except for detonator). Align panel so that bolt axis
   is parallel with pit diameter. (This will prevent the
   bolt halves from blowing out of the pit). Initiate the X-257Q
   mild electric initiator with 5.0 amp.

5. TEST DATA

   5.1 Record date, time, and test conditions. Record condition
   of assembly after initiation. (Complete propagation or not,
   separation of bolts, etc.).

6. GENERAL

   6.1 Safety – The tests specified herein are hazardous and
   shall be conducted with adequate protection to personnel and
   with all appropriate safety precautions.

Prepared by: *E.I Lindberg*   Approved by: *C.R. Platt*
       E. I. Lindberg   C. R. Platt

                                    W. A. McPhee
                                    W. A. McPhee

Appendix C

TEST PROCEDURE

WATERPROOFNESS TEST AT 500 FT DEPTH AND
FUNCTIONAL TEST AT 50 FT DEPTH

AEROJET-GENERAL CORPORATION
Engineering Division
Downey, California

W.O.R. 3324-01-140   19 March 1968

TEST PROCEDURE
WATERPROOFNESS TEST AT 500 ft. DEPTH and
FUNCTIONAL TEST AT 50 ft. DEPTH

1. SCOPE

The objective of these tests is to demonstrate

a. System waterproofness and structural integrity at
    500 foot water depth.
b. System functioning at 50 foot water depth.

2. APPLICABLE DOCUMENTS (AGC)

2.1 Aerojet-General Drawings

1215513	S&A Device
1215404	Explosive Lead Assembly
1215408	Junction Block
1215440	Explosive Bolt Assembly
1215577	Firing Panel Assembly
1215305	Cartridge Assembly, Embedment Anchor

2.2 Subcontractor Drawings

Marsh and Marine P/N K-12845 Cable Assembly

3. TEST REQUIREMENTS

3.1 Test Specimen - The test specimen shall consist of one (1)
1215513 S&A Device (one INERT loaded for the 500 foot water-
proofness test and one LIVE unit for test firing at 50 foot
depth), three (3) each 1215404-1 Explosive Leads 24" lg., two (2)
each 1215404-3 Explosive Leads 24" lg., one (1) 1215408 Junction
Block and two (2) 1215440 Explosive Bolts, plus steel blocks
simulating the reaction vessel and cable connecting lug and a

simulated 1215305 Cartridge Assembly; all mounted on an aluminum panel as shown in Figure C-1, Test Setup. One (1) Marsh and Marine Cable Assembly P/N K-12840 will lead from the Firing Panel P/N 1215577 located on the test platform (boat) to the S&A device.

3.2 Instrumentation - None

3.3 Environment - The test panel shall be submerged in sea-water to a depth of 500 feet and 50 feet respectively for the tests.

4. PROCEDURE

4.1 General - Assemble the components as shown in Figure C-1.

a. Use the INERT loaded S&A Device for the 500 foot water-proofness test.
b. Use the LIVE loaded S&A Device for the 50 foot test firing.

Tighten the explosive bolts to approximately 50 foot-lbs.

Install the explosive lead fittings into their respective locations, push the boosters home and tighten the Swagelok fitting nuts 3/4 of a turn. Install clamps around explosive leads at appropriate locations.

4.2 Submergance - Attach one end of the firing cable to the bulkhead connector on the S&A device and the other end to the connector on the Firing Panel. Assure that the Firing Panel is supplied with 110 V AC. Leave the master power switch off. Lower the test panel overboard, and turn on the master power switch (amber light on).

When panel has reached below the surface, turn selector switch to "TEST 1" position, trip "calibration" switch and balance the "Test-Calib" meter by adjusting the "BAL" screw. When panel is approximately 25 feet below the water line turn on ARM COMMITTMENT for approximately 1 minute while the panel is being lowered. If some delay occurs in lowering the test panel, release the ARM committment switch. Turn Test-Calib knob to Test 1 and Test 2 respectively and turn on READ switch. Null will determine if arming has occurred. If not armed, needle will be off scale.

After reaching desired depth, turn center knob to READY and if all conditions are okay, throw the DET ARM (red light on), give fire signal and count down and turn on FIRE (firing circuit) switch. Lights at DET 1 and DET 2 should go on indicating that detonators fired. This can be verified by testing the bridgewire circuits again.

Turn off all switches and retrieve the test panel.

C-3

CABLE ASSEMBLY
P'N K-12840

ALUMINUM PANEL
APPROXIMATELY 2 BY 3 FT

SAFE/ARM DEVICE
P'N 1215513

EXPLOSIVE LEAD ASSEMBLY
P'N 1215404-1

SIMULATED
CARTRIDGE
ASSEMBLY
P/N 1215305

EXPLOSIVE LEAD ASSEMBLY
P/N 1215404-2

JUNCTION
BLOCK
P'N 1215408

EXPLOSIVE LEAD ASSEMBLY
P/N 1215404-3

SIMULATED CABLE
CONNECTOR LUG

SIMULATED REACTION
VESSEL (ATTACHED TO PANEL)

EXPLOSIVE BOLT ASSEMBLY
P/N 1215440

Figure C-1. Test Setup.

C-4
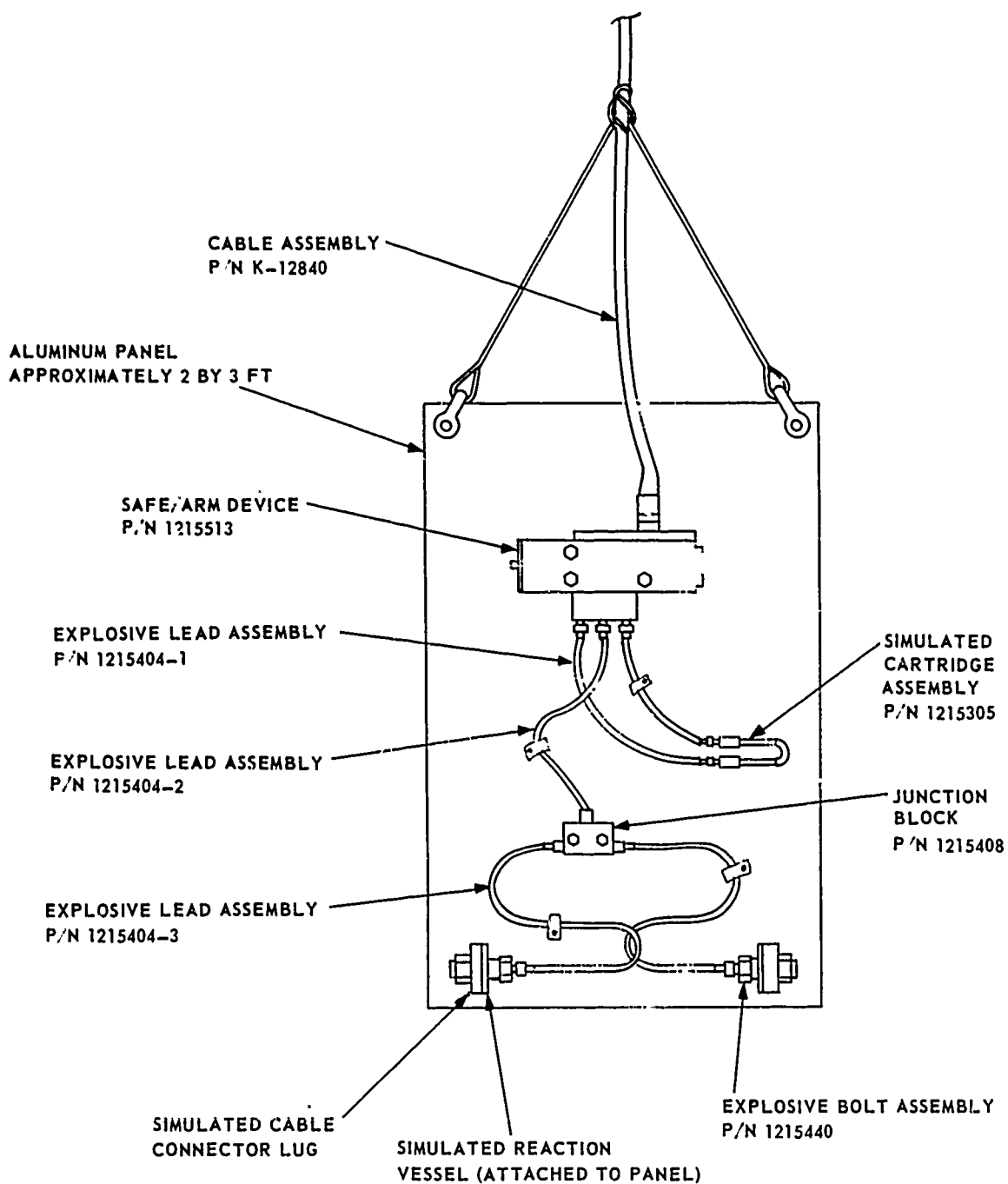
5. TEST DATA

    5.1 <u>Record date, time, and test conditions</u>

    5.2 On the 500 ft test, allow the outside of all test panel
    components to dry thoroughly and then disassemble the test
    setup and examine components for evidence of water entry.

    5.3 On the 50 ft test, observe and record the condition of
    the various components to determine proper functioning, _cc.

6. GENERAL

    6.1 <u>Safety</u> - The tests specified herein are hazardous and
    shall be conducted with adequate protection to personnel and
    with all appropriate safety precautions.

Prepared by: _E. I. Lindberg_____   Approved by: _C. R. Platt_____
              E. I. Lindberg   C. R. Platt

                                                   _W. A. McPhee_____
                                                    W. A. McPhee

Appendix D

TEST PROCEDURE

DETONATOR SENSITIVITY TESTS (BRUCETON TEST)
S/A DEVICE; EMBEDMENT ANCHOR SYSTEM

Test No. 1325-1

AEROJET-GENERAL CORPORATION

Engineering Division

Downey, California

W.O.R. 3324-01-140   10 January 1968

TEST PROCEDURE
DETONATOR SENSITIVITY TESTS (BRUCETON TEST)
S/A DEVICE; EMBEDMENT ANCHOR SYSTEM

1. **SCOPE**

   The object of this test is to determine the detonator-explosive train safety and reliability.

2. **APPLICABLE DOCUMENTS**

   2.1 **Aerojet-General Drawings**

1215513	S&A Device, Embedment Anchor System
	Slide S&A Device
1215395	Housing, S&A Device

   2.2 **MIL-SPECS**

   NAVORD REPORT 2101 - Statistical Methods Appropriate for Evaluation of Fuze Explosive Train Safety and Reliability.

3. **TEST REQUIREMENTS**

   3.1 **Test Specimens** - The test specimen shall consist of a simulated slide with one each D3A2 detonator positioned over block simulating S&A housing with 5 grains/foot MDF installed per Figure D-1. The specimen shall be placed on its side so that an aluminum witness plate can be placed perpendicular to the face of the MDF. A steel back-up plate shall be placed behind the witness plate.

   3.2 **Witness Plates** - shall be 2024-T4 aluminum.

   3.3 **Instrumentation** - None

Figure D-1. Test Setup.
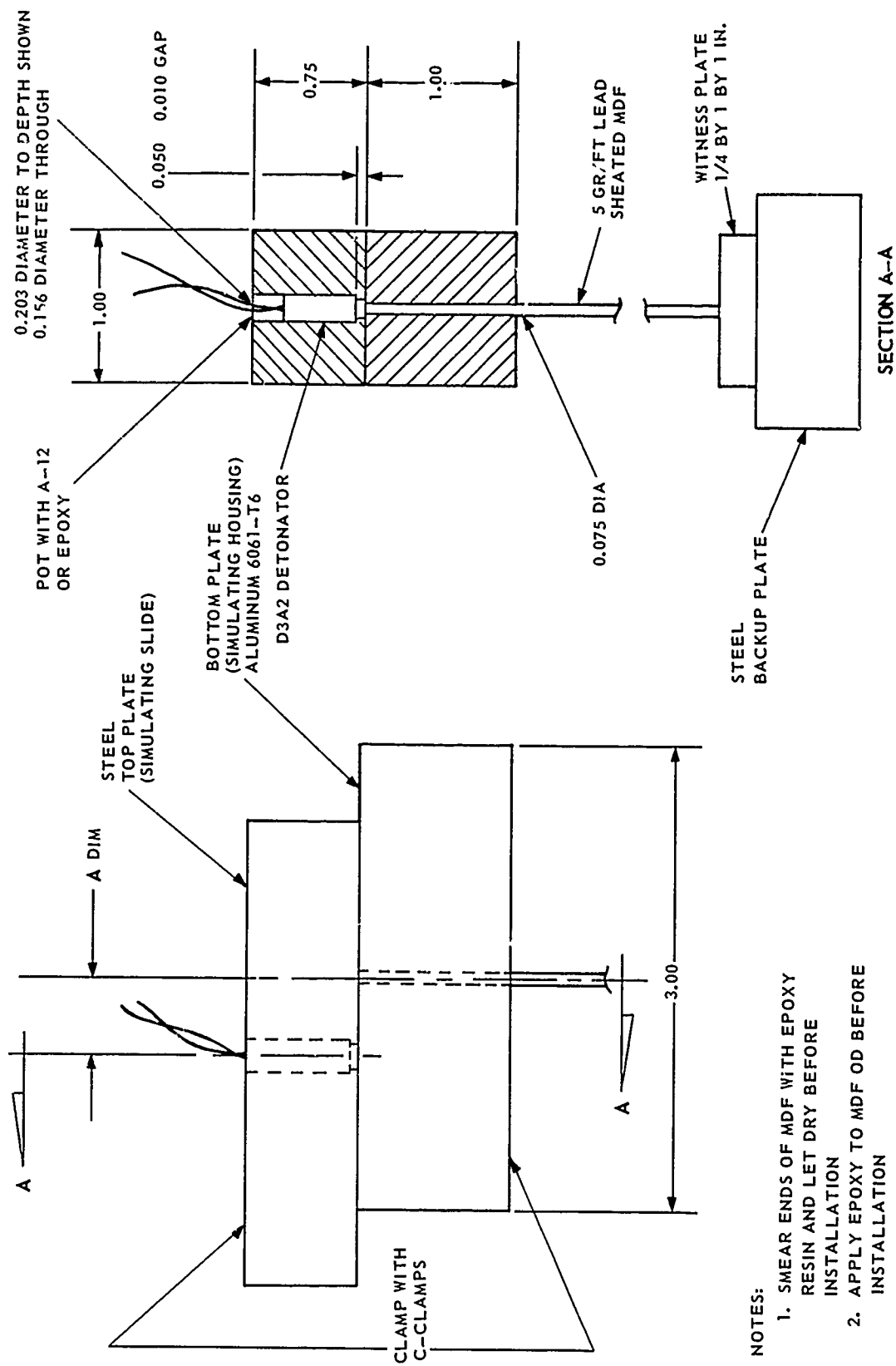
NOTES:

1. SMEAR ENDS OF MDF WITH EPOXY
   RESIN AND LET DRY BEFORE
   INSTALLATION
2. APPLY EPOXY TO MDF OD BEFORE
   INSTALLATION

3.4 Environment - Ambient temperature and humidity.

4. PROCEDURE

    4.1 General - The tests shall be conducted as outlined in
Appendix A of NAVORD Report 2101. Assemble test specimen per
Figure D-1 setting detonator to MDF distance (A) at 3/16 inches
(anticipated mean). Notify Project Engineer before starting
any tests. Set up test specimen in chamber with witness
block as shown. Initiate detonator with a minimum of 5
amperes.   Examine and note condition of bottom plate, MDF
face or witness plate after each test.

    The distance for the next test will be determined after the
result of the preceeding test is known. The anticipated
"up-down distance" (increment "d") is set at 1/32 inch.

5. TEST DATA

    5.1 Record date, time, and test condition. Record condition
of components. Record depth of witness plate dent as applicable
using dial depth indicator.

6.

    6.1 Safety - The tests specified herein are hazardous and
shall be conducted with adequate protection to personnel and
with all appropriate safety precautions.

Prepared by: _E. I. Lindberg_ (signature)
                 E. I. Lindberg

Approved by: _C. R. Platt_ (signature)
                C. R. Platt

                W. A. McPhee (signature)
                W. A. McPhee

Appendix E

TEST PROCEDURE

EXPLOSIVE BOLT SEPARATION
EMBEDMENT ANCHOR SYSTEM

Test No. 1325-2

AEROJET-GENERAL CORPORATION

Engineering Division

Downey, California

W.O.R. 3324-01-140   11 January 1968

TEST PROCEDURE

EXPLOSIVE BOLT SEPARATION

EMBEDMENT ANCHOR SYSTEM

1. SCOPE

The object of this test is to demonstrate the separation
capabilities and conditions of separation of the explosive
bolts installed and fired under simulated conditions.

2. APPLICABLE DOCUMENTS

2.1 Aerojet-General Drawings

    1215439   Bolt, Explosive
    1215440   Bolt, Explosive Assembly

3. TEST REQUIREMENTS

3.1 Test Specimens – The test specimen shall consist of an RDX
loaded bolt P/N 1215440 assembled in plates simulating the
embedment anchor reaction vessel and cable connector lug as shown
in Figure E-1.

3.2 Instrumentation – None.

3.3 Environment – The entire assembly shall be submerged in
water for firing.

4. PROCEDURE

4.1 General – Assemble test specimen per Figure E-1. Torque the
nut to 150 ft-lb. Install pigtail assembly P/N 1215420. Submerge
in 5 gallon container filled with water located in test pit.
(The electric initiator at the end of the pigtail

E-2
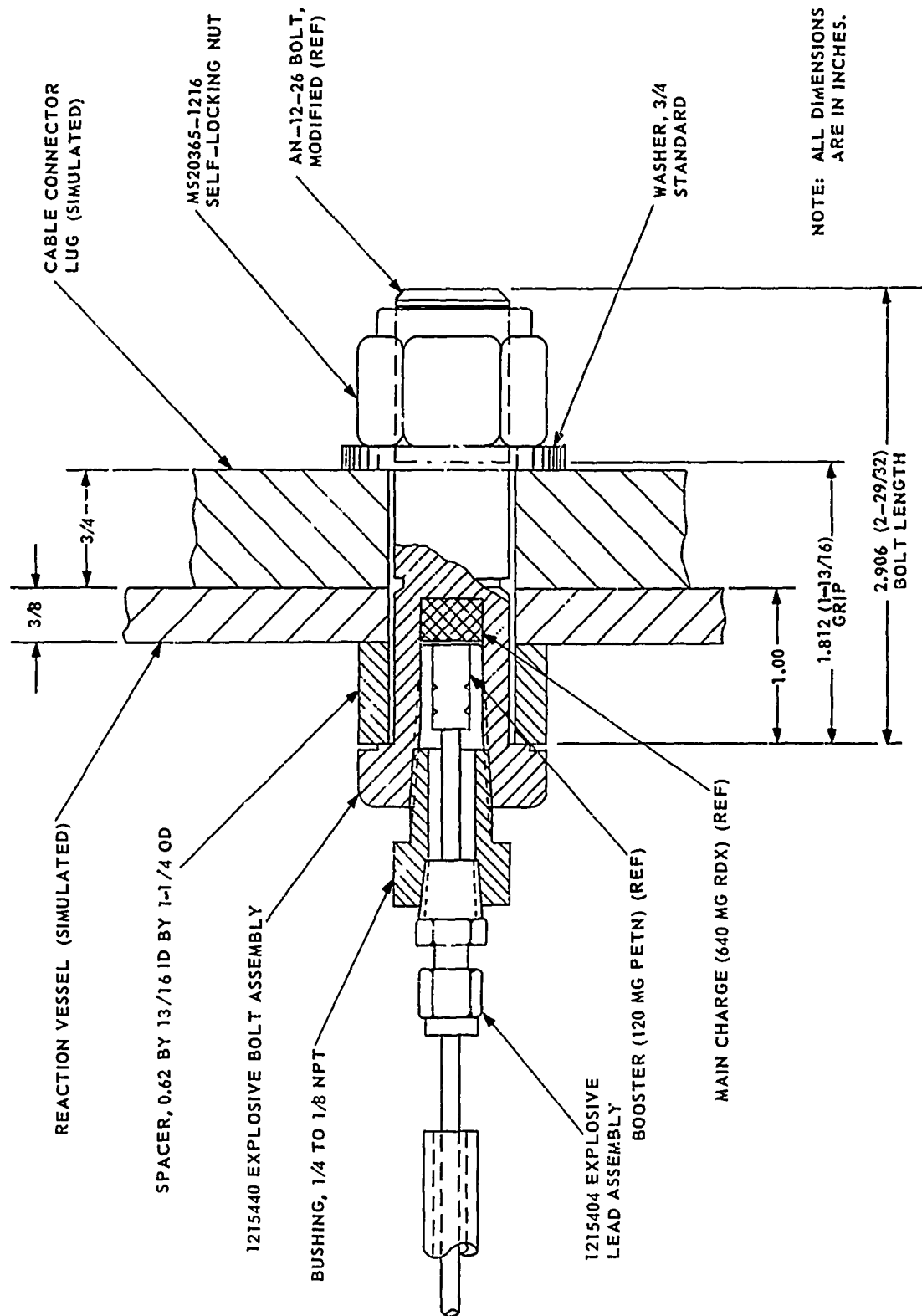
Figure E-1. Explosive Bolt Installation.

CABLE CONNECTOR
LUG (SIMULATED)

MS20365-1216
SELF-LOCKING NUT

AN-12-26 BOLT,
MODIFIED (REF)

WASHER, 3/4
STANDARD

NOTE: ALL DIMENSIONS
ARE IN INCHES.

REACTION VESSEL (SIMULATED)

SPACER, 0.62 BY 13/16 ID BY 1-1/4 OD

1215440 EXPLOSIVE BOLT ASSEMBLY

BUSHING, 1/4 TO 1/8 NPT

1215404 EXPLOSIVE
LEAD ASSEMBLY

BOOSTER (120 MG PETN) (REF)

MAIN CHARGE (640 MG RDX) (REF)

3/4

3/8

1.00

1.812 (1-13/16)
GRIP

2.906 (2-29/32)
BOLT LENGTH

E-3

connector will be outside the 5 gallon container). Rotate
test specimen so that bolt axis is parallel with pit dia-
meter. It is anticipated that bolt halves will be pro-
pelled at high velocities. Initiate the X-257Q mild
electric initiator with 5.0 amp.

5.   TEST DATA

    5.1   Record date, time and test condition. Record condition
        of assembly after initiation (complete breakaway or not).

6.   GENERAL

    6.1   <u>Safety</u> - The tests specified herein are hazardous and
        shall be conducted with adequate protection to personnel
        and with all appropriate safety precautions.

Prepared by: _E. I. Lindberg_

Approved by: _C. R. Platt_

W. A. McPhee

Appendix F

TEST METHODS FOR EFFECTING A PRESSURE AND RF SEAL ON
SAFE/ARM DEVICE TOP CAVITY

A preliminary check with internal air pressure on joints using Metex Pola-
sheet (RF gasket material) showed that the joints leaked when bolts were
tightened to a torque of 5 and 10 in.-lb. No leaks were observed at 15 in.-
lb of torque.

To reproduce actual conditions, a pressure chamber was set up in which the
safe/arm housing could be subjected to an external water pressure of 250
psi (simulating a depth of approximately 560 ft). Tests were conducted in
this chamber, as shown in Table F-1.

Table F-1. Test Data.

Test No.	Date (1968)	Remarks
1	13 March	RF-type gasket (Polasheet); bolts tightened to a torque of 20 in.-lb; leaked approximately 5 cc overnight; pressure was 250 psi at 4:30 pm and had dropped to 0 by 8:00 am.
2	14 March	RF-type gasket with conductive epoxy on both sides; bolts tightened to a torque of 10 in.-lb -- higher torque not feasible because gasket "squashed" out; epoxy cured for 1 hr at 180°F; pressure for 10 min at 250 psi; leaked approximately 4 cc.
		Use of epoxy on RF gaskets is undesirable because gasket flows too much and re-moval of cover is difficult because epoxy bonds to metal; lid had to be pried from housing with screwdriver and surfaces had to be filed and sandpapered clean.

Table F-1. Test Data (Continued).

Test No.	Date (1968)	Remarks
3	14 March	Wire-type gasket consisting of 0.031 in. diameter Sn 50 solder wire with a coat of Grip Cement on the surface; bolts tightened to a torque of 25 in.-lb; pressurized for 1 hr; leaked approximately 2cc; suspected leak at bulkhead connector or porosity at boss on cover plate; connector boss was remachined and apparent holes around plate boss were sealed.
4	14 March	Wire-type gasket as in Test No. 3 except no Grip Cement used; left in 28 hr; pressure 250 psig at 4:30 pm on 3/14/68 and 100 psig at 8:00 am 3/15/68; leaked approximately 2 cc; suspected leak at bulkhead connector because silicone grease had oozed out at inside of threads; used solid coverplate to prevent leak at bulkhead connector or plate boss interfering with tests on gasketing for top plate.
5	15 March	Wire-type gasket as in Tests No. 3 and 4 with silicone grease on surfaces; pressure for 1 hr; no observable leaks.
6	15 March	Wire-type gasket as in Tests No. 3, 4, and 5 except no grease on surfaces; pressure to 250 psig at 4:00 pm on 3/15/68; pressure had dropped to 0 at 8:00 am on 3/18/68; no observable leak except for one drop of water which was believed to have come from a threaded hole when lid was removed.

Appendix G

TEST PROCEDURE

PROPELLANT-ACTUATED CORAL ANCHOR

AEROJET-GENERAL CORPORATION
Ordnance Division
11711 Woodruff Avenue
Downey, California 90241

AD 3324-01(A)-TP   25 June 1968

TEST PROCEDURE
PROPELLANT-ACTUATED CORAL ANCHOR

1. SCOPE

This test procedure is to identify significant tasks to be accomplished in
conducting propellant-actuated coral anchor test operations. It is under-
stood that many of the tasks will be accomplished jointly by the Program
Monitor's office, USNCEL; the Navy Project Office, Naval Ordnance Unit
(NOU), Key West Naval Station; Point Mugu Naval Air Station, Underwater
Camera Unit (UCU); and the prime contractor, the Aerojet-General Cor-
poration. Operations shall be conducted aboard the USS Penguin (ASR-12).
It is further understood that because of technical or contractual require-
ments, other tasks, such as anchor design and ordnance installation modi-
fications by Aerojet and coordination and scheduling by the Navy, must be
accomplished independently by the individual organizations. The various
task responsibilities are defined wherever possible or prudent throughout
this document.

2. APPLICABLE DOCUMENTS

The following documents of the issue or release in effect at the time of
publication of this Test Procedure shall form a part of this document to
the extent defined herein.

2.1   Governmental Documents

MIL-R-398 (Type B)   RDX

MIL-P-387A   Pentaerythrite Tetranitrate
                                (PETN)

G-2

2.2   Aerojet Document

Preliminary Instruction Manual, "Ordnance Subsystem, Embedment
Anchor System," April 1968.

2.3   Aerojet Drawings

1215443-1	Shear Pin
1215404-1	Explosive Lead Assembly
1215513-1	Safe and Arm Device Assembly
1215440-1	Explosive Bolt Assembly
1215314-1	Plate Shackle
1215503-1	Projectile Assembly, Coral Embedment Anchor
1215386-2 & -3	Embedment Anchor Assembly
1215358-1	Embedment Anchor Subassembly
1215305-3	Cartridge Assembly Embedment Anchor
1215907-1	Explosive Pigtail Assembly
1215399-1	Booster Cup Assembly
1216289-1	Safe and Arm Device Simulator
1215408-1	Junction Block
1215245-1	Breech Block
1215420-1	Pigtail Assembly with Electric Detonator Attached

3.   OBJECTIVE

The purpose of the test program is to develop engineering test data in antici-
pation of further design configuration modifications. Therefore, these tests
are considered to be experimental in nature and the various aspects of the
embedment anchor system (P/N 1215386-2 and -3) being subjected to engi-
neering investigation and evaluation are defined.

3. 1   Propulsion Subsystem Development - One objective of this operation is to develop the primary propulsion subsystem described in the Preliminary Instruction Manual, "Ordnance Subsystem, Embedment Anchor System." Specific areas of interest are the energy translation properties of the propelling charge (Ballistic Lot WC870) with respect to both the internal and external ballistics, ignition burn delay characteristics, and variations in "shot-start" pressures as related to holdback shear pin configuration (P/N 1215443-1), as well as downstage propagation of the ordnance interlink (P/N 1215404) between the safe/arm device (S&A) (P/N 1215513-1) and explosive bolts (P/N 1215440-1) at the equalizing bridle plate shackles (P/N 1215314-1).

3. 2   Projectile Dynamics - Another objective is to investigate the coral penetrator (P/N 1215503-1) dynamics during launch, acceleration, impact, and penetration. The launch and acceleration dynamics will provide setback design criteria relating to structural design modifications that may be applied to future coral anchor concepts. The negative acceleration dynamics will provide empirical data for developing more rigorous penetration formulas. Maximum penetration into the various inorganic sea floor mediums as well as into coral formations are of particular importance. Subsequent test operations may investigate similar criteria for modified design concept of coral penetration during these tests.

3. 3   Launch Vehicle Dynamics - In conjunction with the investigation of penetrator dynamics, data concerning the dynamic behavior of the launch vehicle (P/N 1215358-1) will be developed. Such information as recoil acceleration and velocity are of particular interest.

3. 4   Holding Capability - The maximum holding capability of the embeded projectile will be established during these tests. The holding data obtained during these tests is fundamentally important to the success of the program. Holding capability testing shall be accomplished as prescribed in Paragraph 4. 6. 10.

4.   TEST OPERATIONS

4.1   General - It is anticipated that four individual test firings will be accomplished during the testing period of 8 July through 19 July 1968. Only the first of the four experimental firings is explicitly defined.   The test vehicle configuration and the test criteria for the three subsequent test firings will be contingent upon data obtained during each of the previous tests.   There are general tasks that must be performed which are common to each test; they are briefly outlined.   The chronological order in which significant events must be accomplished follows:

     a.   Select test site and survey sea floor (NOU and Aerojet).

     b.   Coral anchor projectile modification (NOU).

     c.   Complete anchor's structural assembly (Aerojet).

     d.   Rig the ship as required (ASR-12).

     e.   Conduct the test (ASR-12, NOU, NCEL, and Aerojet):

          (1)   Position the ship on station (ASR-12).

          (2)   Prepare ship's rigging for launch operation (ASR-12 and Aerojet).

          (3)   Install propellant (Aerojet).

          (4)   Launch anchor test vehicle (ASR-12 and Aerojet).

          (5)   Establish instrumentation module position on sea floor (ASR-12 and UCU).

          (6)   Photograph test apparatus arrangement on sea floor (UCU).

          (7)   Fire test anchor (Aerojet).

          (8)   Photograph posttest details (UCU).

          (9)   Recover instrumentation equipment (ASR-12).

(10) Recover launch vehicle (ASR-12).

(11) Photograph implanted projectile (UCU).

(12) Set marker buoys (projectile, piston, and area marker) (NOU).

(13) Apply load to test holding power (ASR-12).

(14) Recover projectile and piston (ASR-12).

(15) Photograph sea floor after anchor has been removed (UCU).

(16) Obtain samples of coral material from area penetrated by anchor (NOU).

f.   Evaluate test data, assess any damage, rework as required, and reassemble for next operation (Aerojet, NCEL, and NOU).

4.2   Test Projectile Modification - The coral anchor projectile assembly shall be modified in accordance with Drawing 1215503-1 as corrected by Aerojet on 4 June 1968. The modification must be accomplished prior to any significant anchor system assembly, and it is anticipated that this work will be done by the Key West Naval Ordnance Unit facility.

4.3   Test Site Selection and Sea Floor Survey - This task will be accomplished jointly by NCEL and Aerojet. It is understood that the NOU facility will provide support vessels and personnel transportation as required for their operation.

After the test area is selected, the sea floor composition shall be assessed. Fundamental criteria in site selection snall include:

a.   Nominal water depth of 50 ft; allowable limits of 40-ft mean low water and 55-ft mean high water.

b.   Minimum bottom composition thickness of 10 ft of coral average area coplanar contour of less than 15° with respect to horizontal.

c.   Minimum water clarity, of 30-ft visibility on the sea floor.

> Note: This requirement may be super-
> seded by mutual agreement of Aerojet
> and NCEL project engineers.

4.4   Anchor Structure Assembly - It is anticipated that structure assembly (or reassembly for subsequent tests) will be accomplished either aboard ship or in a designated shore area, as applicable, by Aerojet personnel utilizing Navy-operated heavy-equipment support such as fork-lift, mobile cranes, or ship's boom. This task will require approximately 8 hours. The embedment anchor assembly will be in accordance with the configuration shown on Drawing 1215386-3 and will include the modified coral projectile assembly, Drawing 1215503-1. It should be noted that the ordnance installation defined by Drawing 1215386-3 will not be accomplished until immediately before launching operations.

4.5   Ship Rigging - Any shipboard rigging or equipment modification required for the Navy vessel to be used will be accomplished concurrently with the anchor structure assembly.

4.6   Test Operations - In order to facilitate the test instrumentation requirements, it is recommended that a two-point mooring system be used by the Navy vessel for each test. The operating vessel must be positioned such that test equipment can be lowered to the bottom in 50 ft of water and arranged in accordance with Figures G-1 and G-2.

4.6.1   Install Ordnance - The ordnance components shall be installed last, just prior to lowering the anchor over the side. This task will be accomplished by Aerojet personnel. The ordnance components in the first test will consist of the following:

4.6.1.1   Primary propulsion system cartridge (P/N 1215305-3) consisting of approximately 6 lb of double-base smokeless propellant (Ballistic Sample WC870), 18-in., 20-gr/ft pyrocore igniter element, and two X310-J nonelectric mild-end primers.

4.6.1.2   Two explosive bolt assemblies (P/N 1215440) consisting of 400 mg RDX in accordance with MIL-R-398, Type B.
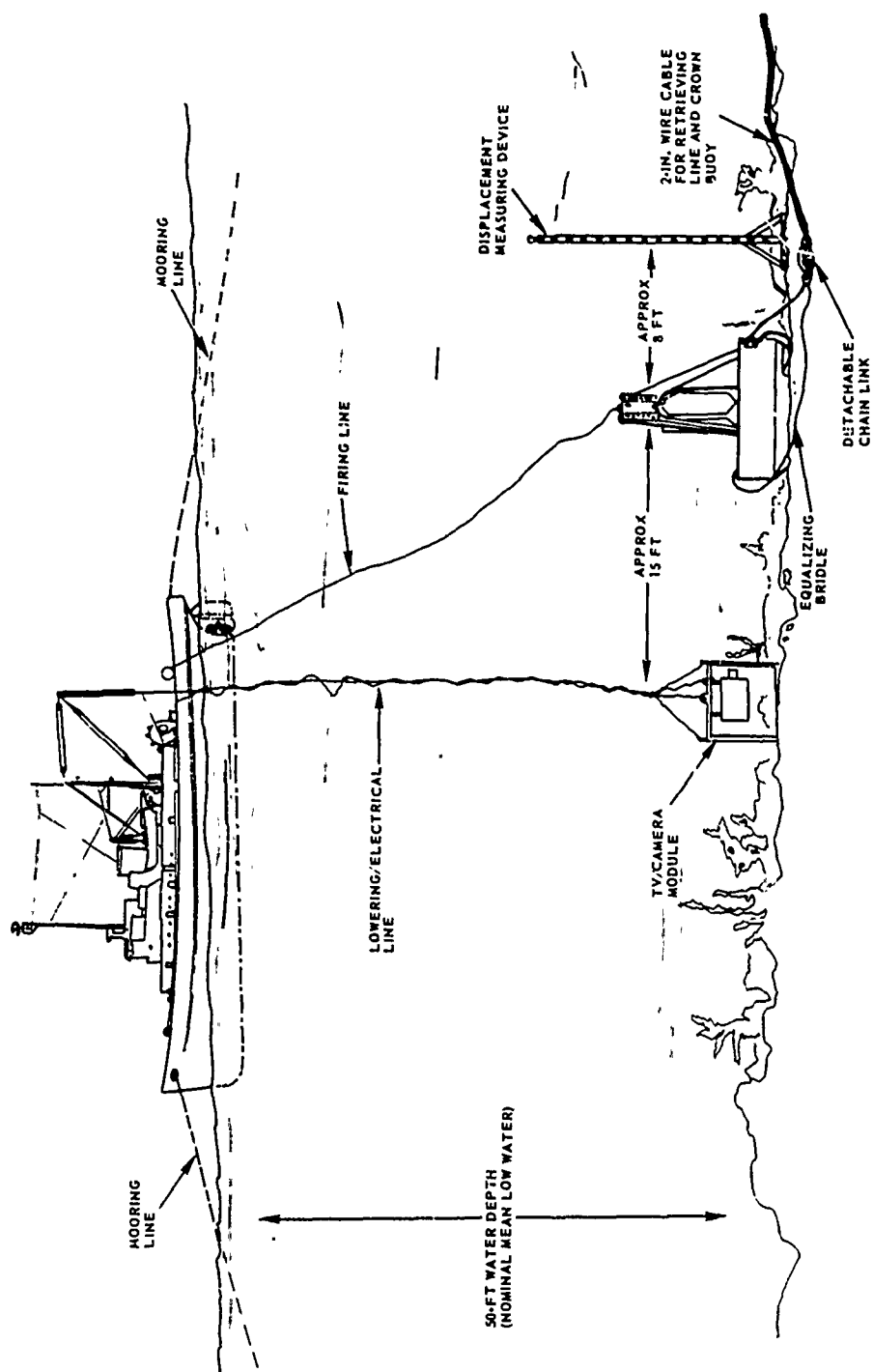
Figure G-1. Test Arrangement Before Firing.

MOORING LINE

FIRING LINE

DISPLACEMENT MEASURING DEVICE

2-IN. WIRE CABLE FOR RETRIEVING LINE AND CROWN BUOY

APPROX 8 FT

APPROX 15 FT

DETACHABLE CHAIN LINK

EQUALIZING BRIDLE

TV/CAMERA MODULE

LOWERING/ELECTRICAL LINE

MOORING LINE

50-FT WATER DEPTH (NOMINAL MEAN LOW WATER)

CROWN BUOY

CROWN BUOY ANCHOR

ANCHOR

RETRIEVAL WIRE

PLATE SHACKLE

2-IN. WIRE CABLE

TEST ANCHOR

TV/CAMERA MODULE

FIRING LINE

PREVAILING DRIFT OF SHIP

ANCHOR

Figure G-2.   Top View of Test Arrangement Before Firing.

4.6.1.3   Five explosive interlink leads (P/N 1215404) consisting of 10-gr/ft PETN mild detonating fuze and ten booster assemblies (P/N 1215399-1) containing 110 gm PETN each per MIL-P-387, Class 2.

4.6.1.4   Two 257-Q electric detonators containing 1.2 gr lead azide carrier charge. The electrical properties are 0.44 ohms resistance, 0.8 amp all-fire, and 0.3 amp no-fire. Function time is 4 msec at 5.0 amp.

4.6.1.5   One S&A simulator (Drawing 1216289-1). The ordnance material will be utilized aboard ship in the quantities and configurations noted. The following ordnance safety procedures will be observed:

    a.   Aerojet's firing officer shall inform the ship's captain that ordnance is being brought aboard.

    b.   Aboard ship all explosives shall be stored in suitable magazine lockers or other spaces designated by the captain or his representative.

    c.   At the appropriate time during test vehicle assembly, permission shall be obtained from the ship's captain to move the explosives from storage and to the deck for loading into the launch vehicle.

    d.   All radio transmitters, radars, or any other sources of RF energy radiation shall not be operated while the ordnance components are on deck.

    e.   All nonessential personnel shall be advised to stay clear of the anchor vehicle during loading operations.

    f.   Smoking shall be prohibited while the explosives are on deck.

g. The propulsion subsystem ordnance shall be prepared and installed on the anchor test vehicle by Aerojet personnel. All nonessential personnel shall stay clear of the assembly area throughout the assembly and installation procedure, which shall proceed as follows:

(1) The propellant shall be loaded into the main propulsion cartridge assembly (P/N 1215305-3) in a suitable loading area designated by the ship's captain. The prepared cartridge shall be retained in appropriate magazine storage until it is installed into the test vehicle.

(2) Install the S&A simulator (1216289-1) in accordance with Drawing 1215386-3, using three 7/16-20 x 4.0-in.-long hex head bolts with washers.

(3) Install junction block (P/N 1215408-1) on ledge of launch vessel in accordance with Drawing 1215386-3 using two 1/4-20 x 1.4 in.-long hex-head bolts.

(4) Unpackage explosive lead assemblies (P/N 1215404) and install them as follows (Figure G-3).

(a) Install one P/N 1215404-2 explosive lead from No. 1 position on S&A simulator to No. 1 hole on junction block (P/N 1215408).

(b) Install two P/N 1215404-1 explosive leads, one on No. 2 and one on No. 3 position on S&A simulator. Let them hang free.

(c) Attach two P/N 1215404-3 explosive leads, one to each explosive bolt position on the junction block. Let them hang free.

ELECTRICAL POWER SOURCE

FIRING LINE

SAFE-ARM DEVICE
SIMULATOR
P 'N 1215513-1

EXPLOSIVE LEAD ASSEMBLY
P N 1215404-1
(2 REQ D)

EXPLOSIVE LEAD ASSEMBLY
P 'N 1215404-2

EXPLOSIVE BOLT
P 'N 1215440-1
(2 REQ'D)

CARTRIDGE ASSEMBLY
P 'N 1215305-1

JUNCTION BLOCK
P N 1215408

EXPLOSIVE LEAD ASSEMBLY
P 'N 1215404-3
(2 REQ'D)
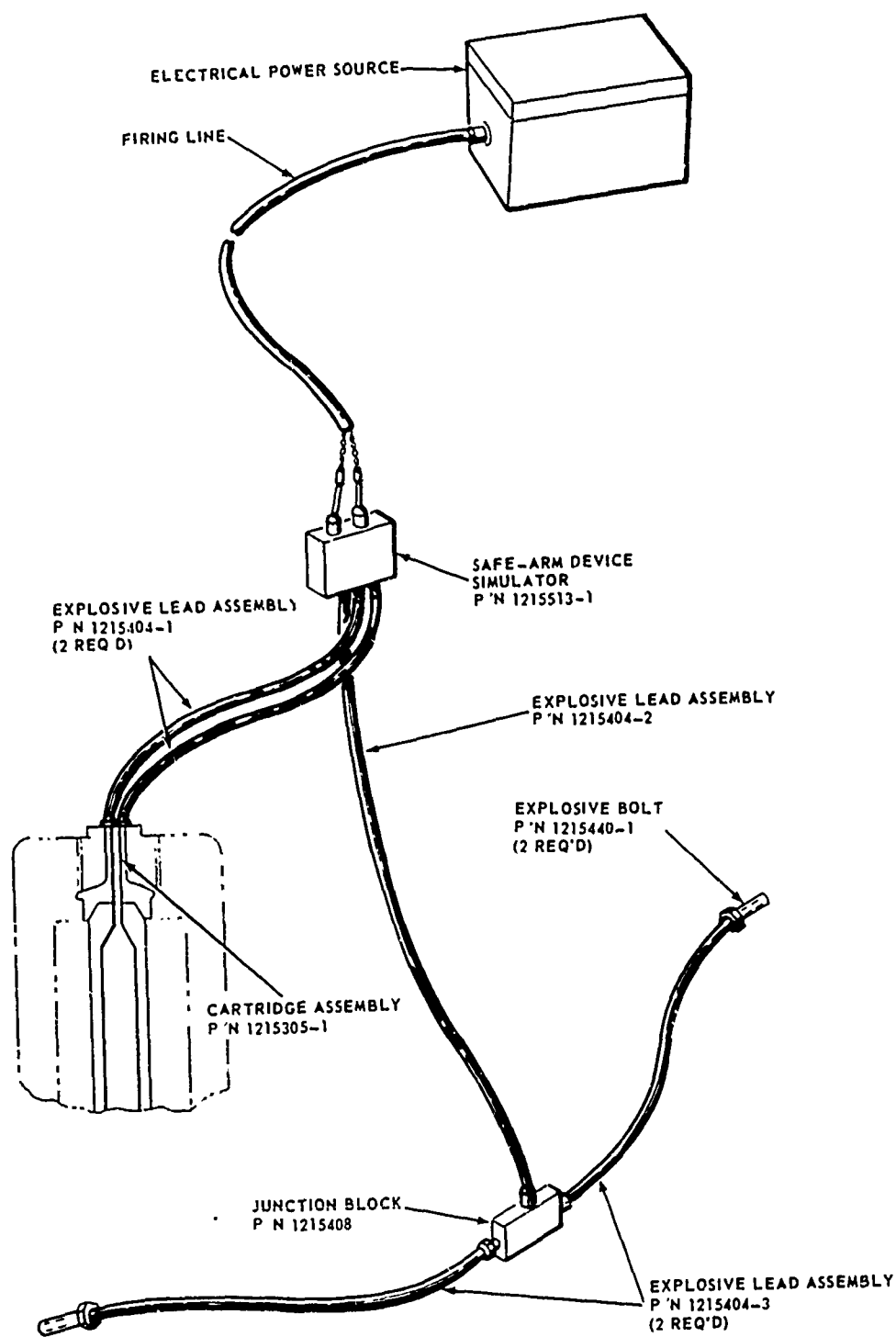
Figure G-3.   Ordnance System.

(5)   After all explosive lead assemblies have been installed (a total of 6 fittings), install the cable clamps at locations provided on the anchor assembly.

(6)   Unpackage and install two explosive bolt assemblies (P/N 1215440) in accordance with Drawing 1215386.

•   At this time and before making any additional ordnance connection, the Aerojet firing officer shall verify with the ship's captain that all rigging has been completed and that the anchor is ready for lowering. When conformation is obtained, Aerojet will proceed with the following hookup operations.

(7)   Unpackage and install explosive bolts (P/N 1215440-1) and attach explosive leads (P/N 1215404-3).

(8)   Unpackage and install cartridge assembly (P/N 1215305-3) into anchor assembly barrel and install breech plug (P/N 1215245-1).

(9)   Attach the two explosive leads (P/N 1215404-1) previously installed on the S&A simulator to the cartridge base igniter holes.

(10)   Unpackage and install two pigtail assemblies with electric detonator (P/N 1215420-1) to short-circuited firing line.

        Note: The Aerojet firing officer shall determine and verify that the firing line is properly short-circuited.

(11)   By using a blasting galvanometer or other suitable circuit testing instrument, verify closed circuit continuity in the firing line.

G-13

(12) Install pigtail assemblies (P/N 1215420-1) into S&A simulator.

● The ordnance subsystem is now fully installed. The ship's captain shall be notified by the Aerojet firing officer that the ordnance equipment has been installed and the anchor is ready for launching.

4.6.1.6   All squib checks and firing circuit continuity tests shall be performed after the anchor has been launched and is resting on the sea floor.

4.6.1.7   When installing explosive lead fittings, the following procedures shall be observed.

   a.   Make sure fitting joint nuts are loose on the MDF.

   b.   Apply liberal amounts of Dow Corning grease on threads of brass fitting.

   c.   Push booster into cavity and screw-in fitting using normal installation torque for brass pipe fittings.

   d.   Make sure boosters are fully inserted and then tighten fitting jam nut finger-tight.

   e.   Make a mark on one hex and tighten jam nut one full turn.

```
+-------------------------------------+
|              CAUTION                |
|                                     |
|   Do not over tighten.  Over        |
|   tightening of the jam nut can     |
|   damage the MDF lead.              |
+-------------------------------------+
```

4.6.2   Launch Anchor Test Vehicle - The anchor shall be rigged on deck in such a manner as to be suitable for lowering to the bottom in 50 ft of water. It is recommended that the rigging be such that the 2.0-in.-wire cable test pendant is attached to the anchor equalizing bridle with a detach-able chain link. The end of the pendant shall be attached to a crown buoy by a retrieval cable approximately 80 ft long. A crown buoy anchor shall be attached and rigged over the side of the ship (Figure G-4). The 2.0-in.-wire pendant shall be rigged for running over the side of the ship by being suspended and stopped-off with 21-thread lines.

It is recommended that the anchor be launched as follows:

a.   The ship shall be positioned approximately 200 ft astern of the desired anchor-drop location.

b.   The crown buoy, crown buoy anchor, and retrieval wire shall be dropped into the water and positioned.

c.   The ship shall then be moved slowly forward while the pendant monitor stoppers on the 2.0-in.-wire cable are cut and the wire is allowed to pay out.

d.   When all the cable has paid out, the ship will hold its position.

e.   The anchor vehicle shall be lifted over the side with the ship's main boom and shall be lowered to the bottom, taking care to tend all firing lines and instrument lines to prevent fouling.

f.   When the anchor has reached the bottom and is oriented, it will be inspected by NOU divers to see that the cable and equilizing bridle has layed out properly.

g.   If the fall-block hook was used, remove it from the lowering bridle and return it to the deck.

h.   Lower the photo index device and place it directly opposite the camera location.

TEST ANCHOR

1½x6x37 WIRE CABLE
EQUILIZING BRIDLE

TV CAMERA MODULE

1/2-IN. WIRE ROPE 80-FT LONG
TO CROWN BUOY ANCHOR

1/2-IN. WIRE ROPE 80-FT LONG
RETRIEVAL WIRE TO 2 IN. TEST
PENDANT

EMBEDMENT ANCHOR RIGGED TO
MAIN BOOM. HOIST CABLE FAIRLEADED
FROM CAPSTAN OR SECONDARY WINCH

1000 LB.LWT
CROWN BUOY ANCHOR

RIGGED 2-IN. WIRE CABLE TEST PENDANT
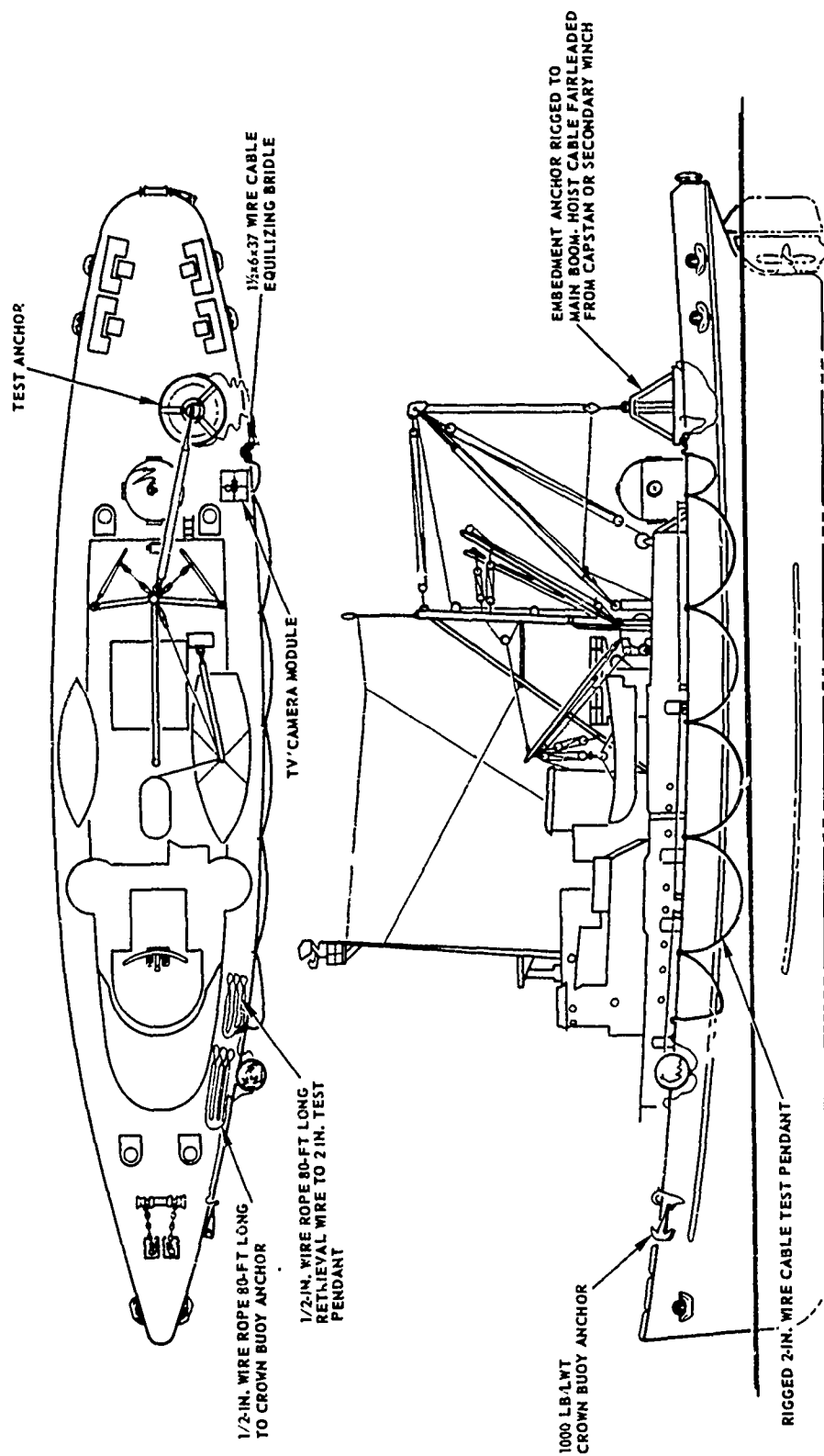
Figure G-4. Plan View Illustrating the Sequence of Operation:
Lower the Crown Buoy Anchor First, the Crown Buoy Next,
and the Embedment Anchor Last.

4.6.3　　Position Camera Module - After the anchor test vehicle has been satisfactorily placed on the bottom and all rigging has been cleared, the ship shall be moved forward approximately 15 ft. The TV/camera module shall be lowered at this point and positioned as shown in Figure G-1. The arrangement shall be inspected by divers. Documentary 16mm motion pictures and 35mm still photos shall be taken of the test equipment and arrangement.

4.6.4　　Fire Anchor - The Aerojet firing officer shall advise the ship's captain that the anchor is ready for firing. It is recommended that the ship move forward in the mooring area approximately 50 ft to prevent any possible damage from anchor recoil. The captain shall advise the Aerojet firing officer when the ship is in the proper location. Upon authorization from the ship's captain the firing officer shall count down from 10 and fire the anchor. The cameras shall be actuated at the appropriate time during the countdown. The firing current shall be provided from a battery, blasting machine, or other suitable power source.

4.6.5　　Test Documentation - The Aerojet firing officer shall advise the ship's captain when it has been determined that all ordnance has functioned and the anchor is considered to be safe. Photo divers shall obtain still and motion pictures of any posttest damage or disarrangement of the test equipment before it is moved.

4.6.6　　Recover TV/Camera Module - When it has been determined that all lines are free and no fouling has occurred, the TV/camera module shall be recovered and placed on deck.

4.6.7　　Recover Anchor Launch Vehicle - The ship shall be moved aft approximately 15 ft to a position over the launch vehicle, which shall be recovered and placed on deck.

4.6.8　　Photograph Anchor Projectile - After the launch vehicle has been recovered and placed on deck, photo divers shall photograph the emplanted anchor projectile and the sea floor area immediately adjacent to the penetration point.

4.6.9   Position and Set Marker Buoys - Before testing the anchor's holding power, position and set two marker buoys to help relocate the penetration point. Attach one to the piston section of the projectile and the other approximately 10 ft away.

4.6.10   Holding Power Test - Holding power operations shall be conducted after the instrumentation module and launch vehicle have been recovered. The operating vessel shall recover the bitter end of the 2-in. pull test cable and apply a sustained pulling force. To measure the applied force a transducer (supplied by NCEL) shall be coupled into the towing hawser at a point between the carpenter stopper and the point of connection to the ship. The arrangement for the holding power test shall be as shown in Figure 5-20. If the water depth is other than the noted 50 ft (nominal), appropriate adjustments shall be made to the working length of the 2-in. test pendant by relocation of the carpenter stopper.

4.6.11   Anchor Projectile and Piston Recovery - After the anchor projectile has been pulled free, recovery of the projectile and piston shall be accomplished by the operating vessel.

4.6.12   Photograph Projectile Penetration Area - After all anchor hardware has been recovered, the hole in the coral formed by the projectile penetration shall be photographed for engineering study. The extent and type of photo coverage shall be determined by the Aerojet project engineer at the test site.

4.6.13   Recovery of Sample Coral Material - Samples of the coral material shall be obtained from the hole formed in the sea floor by the projectile. The coral samples shall be recovered from three points within the penetration profile: the top, the center, and the bottom. All samples shall be identified as to their position in the hole profile relative to a plane at the projectile entrance. All samples shall be approximately 1 cu-ft in size. Depending upon the extent of the coral breakup from the penetration and the removal of the projectile, it may be necessary to utilize a quarry excavation method of sample recovery. In this event, it will be necessary for NOU or EOD diver personnel to prepare suitable explosive charges and to conduct blasting operations. This task is expected to be accomplished by NOU.

4.6.14   Evaluation of Results and Data - All test data, including pull-out versus force-time curve, penetration data, and coral properties data, shall be made available to the NCEL and Aerojet project engineer for review and evaluation. As noted in Paragraph 3, in subsequent tests certain experimental parameters will be varied as a result of the preceeding data.

5.   MALFUNCTION PROCEDURES

In the event of an ordnance system malfunction, the following disarming and recovery safety procedures shall be observed.

Under NO circumstance is the anchor assembly to be recovered until the propulsion subsystem charge has been made SAFE. In the event of an ordnance system malfunction, EOD recovery shall proceed in accordance with Items a through e inclusive. If any one of these items cannot be successfully accomplished, the precise test location shall be recorded, suitable surface marker buoys positioned, and recovery operations abandoned until circumstances are such that a safe recovery can be effected.

a   All firing circuits shall be checked by the Aerojet firing officer for continuity or resistance variation. The firing circuit shall be short-circuited and confirmed at this point.

b.   Allow the undisturbed anchor assembly to remain on the bottom for not less than 30 min.

c.   Divers shall inspect the anchor and note any visual cause for the malfunction. Special attention shall be directed to the firing lead connections, igniter leads, electrical ignition primers, and down-stage explosive bolt leads. (Refer to Figure G-3.)

d.   Any visible damage to ordnance component elements shall be referred to the Aerojet project engineer for evaluation.

e.   The disarming procedure (Figure G-5) shall be as follows:

(1)   First, using suitable wire cutters, divers shall cut each of the MDF ignition leads from the S&A simulator to the main propulsion subsystem cartridge. The leads shall be cut at a point approximately 1 in. from the S&A terminal connection.

(2)   Second, cut each of the MDF igniter leads from the firing lines. Cut these leads at a point approximately 1 in. from the electrical detonator connection. Do not cut the electrical leads from the firing line to the electrical detonator.

(3)   Third, disconnect the MDF down-stage lead to the explosive bolts from the S&A simulator.

f.   When each of these disarming tasks has been accomplished, the anchor system may be considered disarmed. Caution should be observed, however, in recovering the anchor until such time as the nature of the malfunction can be determined and appropriate corrective action can be taken by the project personnel.

6.   TEST DOCUMENTATION

6.1   Data - It is considered mandatory that project personnel participate in the data gathering procedures. Therefore, if more than one vessel is used in the test operation, a suitable means of transporting personnel between support vessels shall be provided. The test data required for each shot shall include:

a.   Projectile-muzzle velocity.

b.   Launch vehicle reaction velocity.

SECOND EOD STEP
CUT EACH MDF LEAD

DO NOT CUT ELECTRICAL
LEADS

FIRST EOD STEP
CUT EACH MDF LEAD

1.00 IN.

1.00 IN

THIRD EOD STEP
DISCONNECT MDF LEAD
FROM S & A SIMULATOR
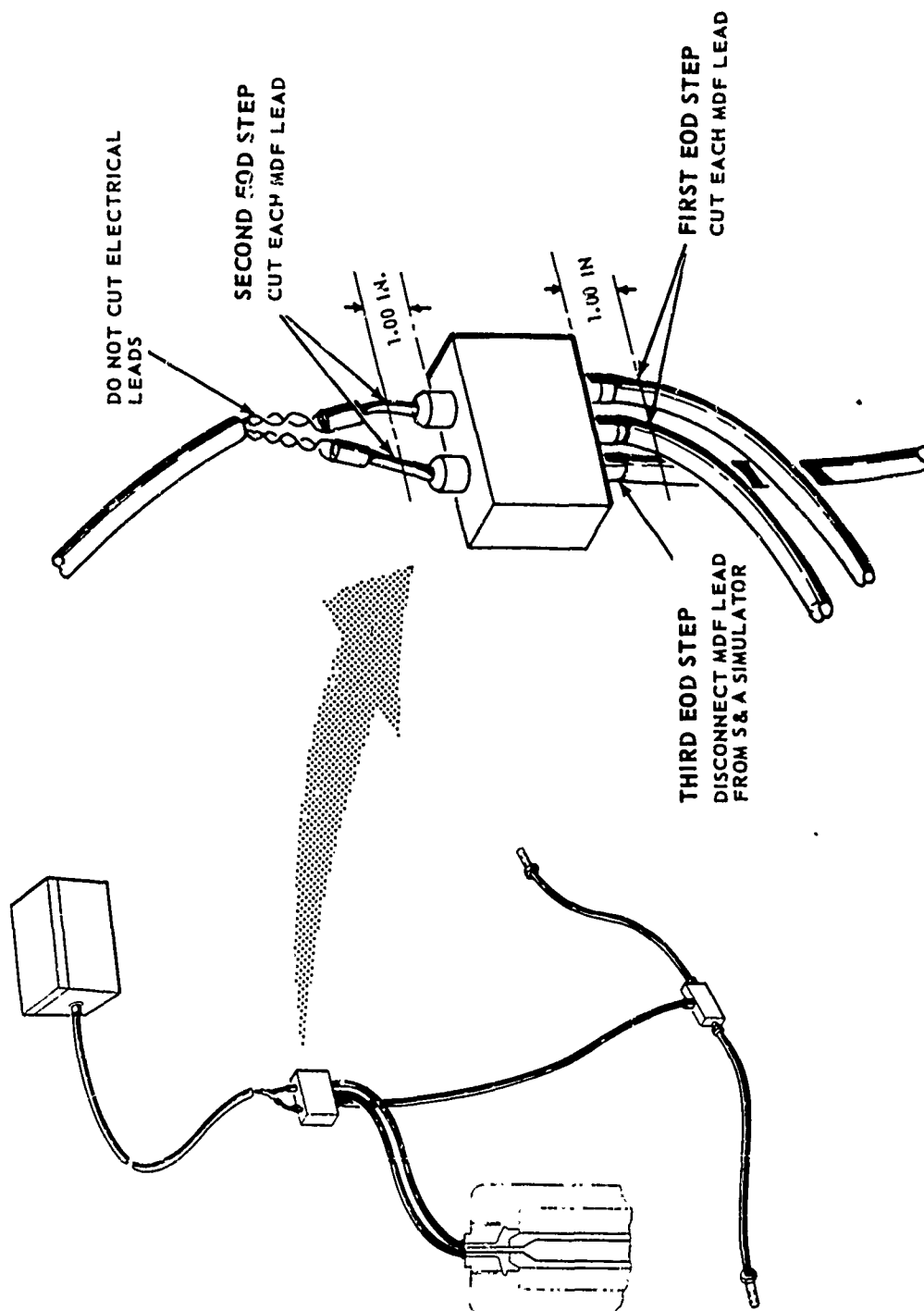
Figure G-5. Disarming Procedure.

G-21

c. Maximum projectile penetration.

d. Incremental holding power.

e. Maximum holding power.

f. Coral material samples from the penetration hole.

6.2 Photography - As noted throughout this test procedure, substantial photographic services shall be required. Underwater services provided by the Point Mugu Underwater Camera Unit shall include:

a. Closed circuit TV coverage with a magnetic tape recording and playback capability.

b. DBM/9 Milliken high-speed camera (400 frames/sec) remote control capability.

c. DBM/9 Milliken 16mm (24 frames/sec) color documentary of pretest and posttest operations.

d. 35mm color still photographs of test apparatus.

e. Hasselblad, superwide angle, 70mm color negative for underwater documentation.

f. Still photo documentary coverage of general surface and on-deck test preparations (provided by NOU).

7. SUMMARY

It is anticipated that four test firings will be accomplished during the test period. Each of the tests shall be defined as engineering experiments with the subsequent tests subjective to, and dependent upon the preceding tests. Variations and modifications to the test apparatus, test procedures, data requirements, test locations, and operational techniques shall be incorporated as required. It is understood that throughout the test operation,

support services as required and as available will be provided by the Naval Ordnance Unit, Key West Naval Station. Technical responsibility for the implementation of test objectives shall be that of the Aerojet-General Corporation, Ordnance Division, Downey, California. Overall coordination of the program shall be under the cognizance of the U.S. Navy Civil Engineering Laboratory, Port Hueneme, California. Support services shall be supplied jointly by the Naval Ordnance Unit, Key West Florida, the USS Penguin (ASR-12), and the Underwater Camera Unit, Point Mugu Naval Air Station, California.

Appendix H

TEST REPORT -- PREQUALIFICATION TESTING OF EMBEDMENT ANCHOR SAFE/ARM DEVICE

H.1 OBJECTIVE

The objective of this environmental test series was to obtain preliminary information on the operation, safety, and integrity of the safe/arm devices.

H.2 SUMMARY OF TEST RESULTS

The prequalification test results demonstrated that the safe/arm devices met the design objectives as stipulated. In the transportation vibration testing, some unexpected minor difficulties were experienced on one unit (Serial No. 16); however, investigation revealed that these conditions were caused by incorrect assembly procedures or problems that could be easily corrected. All units performed satisfactorily, although the units exposed to the temperature/humidity test suffered some degradation. The units that underwent this test were sluggish in arming. Examination showed that oxidation or foreign material on the spring contacts and, to some extent, on the external bulkhead connector pins produced an additional resistance which prevented the meter on the firing panel from registering a complete null, as is the case when positive contact is made. However, this condition did not render the unit nonfunctional; the resistance buildup was small and sufficient amperage was available to initiate the detonators, even with the higher resistance. Nevertheless, this condition should be eliminated. This and other recommended changes are discussed in Paragraph H.8.

H.3 APPLICABLE DOCUMENTS

The following documents form a part of this test report to the extent specified herein.

- Aerojet-General Corporation Drawings

    1215513-1B   Safe/Arm Device Assembly

    1215577-1N/C   Anchor Control Panel Assembly

| 1215907-1N/C | Pigtail Assembly |
| K-12840N/C | Cable Assembly |

● Military Specifications

| MIL-STD-331, Change Notice 2 | Fuze and Fuze Component Environmental and Performance Tests |
| MIL-STD-167 Ships | Mechanical Vibrations of Shipboard Equipment |

H.4 TEST SPECIMENS

The test specimens consisted of 12 safe/arm device assemblies, Part No. 1215513-1B. The serial numbers on the 12 safe/arm devices tested were 1, 2, 3, 4, 5, 7, 8, 9, 11, 16, 17, and 18 (as selected from a lot of 18).

H.5 TEST APPROACH

The 12 test specimens were divided into three groups of four units each and each group was subjected to the environmental and dynamic testing as shown in Figure H-1. The various tests conducted were as follows:

Transportation vibration	Test No. 104, MIL-STD-331
Temperature/humidity	Test No. 105, MIL-STD-331
Salt spray	Test No. 107, MIL-STD-331
Waterproofness	Test No. 108, MIL-STD-331
Static detonator safety	Test No. 115, MIL-STD-331
Shipboard vibration	Type I, MIL-STD-167
Performance test firing	

After each test sequence, and after each axis test in the transportation vibration test, each unit was subjected to an electrical checkout. This was accomplished by actuating the bellows assembly with a hydraulic pump and checking no-arm, arm, and inclinometer functions on the anchor control panel (Part No. 1215577) connected to the safe/arm device by means of the firing cable assembly (Part No. K-12840). Figure H-2 shows the hydraulic water pump setup. The rough checkout data are presented in Tables H-1 through H-12.

S/A DEVICE (12 EACH)

```
                        ┌─────────────┐
                        │  CHECKOUT   │
                        │   TESTS     │
                        └─────────────┘
                               │                    7, 8, 16
                               │              ┌──────────────────┐
                               │─────────────▶│ TRANSPORTATION   │
                               │◀─────────────│   VIBRATION      │
                               │              └──────────────────┘
                               │                    3 EACH

    SEQUENCE 1            SEQUENCE 2            SEQUENCE 3
 4 EACH │ 4, 8, 9, 11   4 EACH │ 1, 16, 17, 18   4 EACH │ 2, 3, 5, 7
  ┌─────────────┐        ┌─────────────┐        ┌─────────────┐
  │   TEMP/      │        │  SHIPBOARD  │        │    SALT     │
  │  HUMIDITY    │        │  VIBRATION  │        │    SPRAY    │
  └─────────────┘        └─────────────┘        └─────────────┘
         │                      │                      │
  ┌─────────────┐        ┌─────────────┐        ┌─────────────┐
  │  SHIPBOARD  │        │   WATER-    │        │  SHIPBOARD  │
  │  VIBRATION  │        │  PROOFNESS  │        │  VIBRATION  │
  └─────────────┘        └─────────────┘        └─────────────┘
         │
  ┌─────────────┐
  │    SALT     │
  │   SPRAY     │
  └─────────────┘
```

                                          1, 2
                               ┌──────────────────┐
                               │ STATIC DETONATOR │
                               │   SAFETY   │
                               └──────────────────┘
                                     2 EACH

                                          5, 16
                               ┌──────────────────┐
                               │ PERFORMANCE   │
                               │ TEST FIRING   │
                               └──────────────────┘
                                     2 EACH

                    ┌─────────────┐
                    │ CLEANUP,   │   3, 4, 7, 8, 9, 11, 17, 18
                    │   ETC.   │
                    └─────────────┘
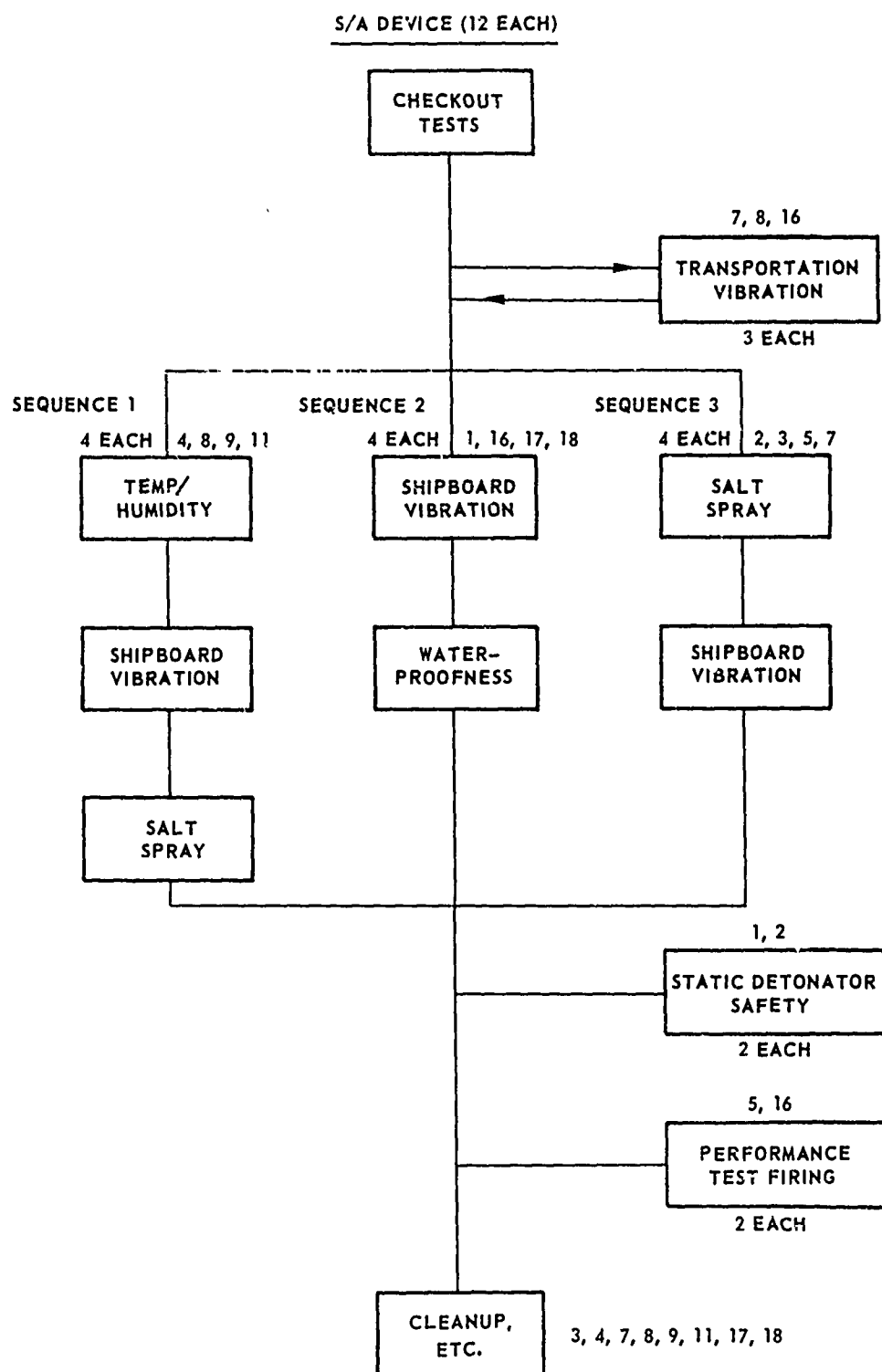
Figure H-1.   Prequalification Environmental Test Plan.

H-3

Table H-1. Embedment Anchor Safe/Arm Device -- Unit 1.

Test	Posttest Checkout	Date	Remarks
Transportation vibration	Safe/arm X axis Y axis Z axis		
Shipboard vibration	Safe/arm	17 Sept 1968	Electrical checkout all right. Both detonators armed at 15-1/2 psig
Waterproofness	Safe/arm	20 Sept 1968	Passed
Static detonator safety	Safe/arm	23 Sept 1968	Passed

Table H-2. Embedment Anchor Safe/Arm Device -- Unit 2.

Test	Posttest Checkout	Date	Remarks
Transportation vibration	Safe/arm X axis Y axis Z axis		
Salt spray	Safe/arm	1 Aug 1968	Electrical checkout all right
Shipboard vibration	Safe/arm X axis Y axis Z axis	17 Sept 1968	Electrical checkout all right. Detonator No. 2 armed at 15 psig; detonator No. 1 armed at 16 psig
Static detonator safety		23 Sept 1968	Passed

Table H-3. Embedment Anchor Safe/Arm Device -- Unit 3.

Test	Posttest Checkout	Date	Remarks
Transportation vibration	Safe/arm X axis Y axis Z axis		
Salt spray	Safe/arm	1 Aug 1968	Electrical checkout all right
Shipboard vibration	Safe/arm X axis Y axis Z axis	17 Sept 1968	Electrical checkout all right. Both detonators armed at 15-1/2 psig
Static detonator safety			

Table H-4. Embedment Anchor Safe/Arm Device -- Unit 4.

Test	Posttest Checkout	Date	Remarks
Transportation vibration	Safe/arm X axis Y axis Z axis		
Temperature and humidity	Safe/arm	16 Sept 1968	Sluggish arming. Detonator No. 1 armed intermittently. Detonator No. 2 all right. Contacts dirty or corroded
Shipboard vibration	Safe/arm X axis Y axis Z axis	20 Sept 1968	Electrical checkout all right. Detonator No. 2 armed at 16 psig; after recycle, Detonator No. 1 armed at 20 psig
Salt spray	Safe/arm	7 Oct 1968	Sluggish arming

Table H-5. Embedment Anchor Safe/Arm Device -- Unit 5.

Test	Posttest Checkout	Date	Remarks
Transportation vibration	Safe/arm X axis Y axis Z axis		
Salt spray	Safe/arm	1 Aug 1968	Electrical checkout all right
Shipboard vibration	Safe/arm X axis Y axis Z axis	17 Sept 1968	Electrical checkout all right; armed at 17 psig
Static detonator safety			

Table H-6. Embedment Anchor Safe/Arm Device -- Unit 7.

Test	Posttest Checkout	Date	Remarks
Transportation vibration	Safe/arm		
	X axis	21 Aug 1968	Failed electrical checkout. Dissassembled, cleaned, and reassembled. Checkout allright electrically.
	Y axis	16 Aug 1968	Passed electrical checkout
	Z axis	23 Aug 1968	Armed at 18 psi. Detonator No. 1 closed, No. 2 opened at 19 psi. Both closed at 19.5 psi. Both switches opened at 18.5 psi on pressure decay
Salt spray	Safe/arm	11 Aug 1968	Electrical checkout all right
Shipboard vibration	Safe/arm X axis Y axis Z axis	17 Sept 1968	Electrical checkout all right. Detonator No. 1 armed at 16 psig; Detonator No. 2 armed at 15 psig
Static detonator safety			

Table H-7. Embedment Anchor Safe/Arm Device -- Unit 8.

Test	Posttest Checkout	Date	Remarks
Transportation vibration	Safe/arm		
	X axis	6 Aug 1968	Electrical checkout all right
	Y axis	7 Aug 1968	Electrical checkout all right
	Z axis	2 Aug 1968	Electrical checkout all right
Temperature and humidity	Safe/arm	16 Sept 1968	Detonator No. 1 was 2.5 small divisions off and Detonator No. 2 was 1.5 small divisions off, indicating dirt on contacts
Shipboard vibration	Safe/arm X axis Y axis Z axis	20 Sept 1968	Electrical checkout completed. Sluggish arming from 17 to 20 psig.
Salt spray	Safe/arm	7 Oct 1968	Sluggish arming (discussed in text)

Table H-8. Embedment Anchor Safe/Arm Device -- Unit 9.

Test	Posttest Checkout	Date	Remarks
Transportation vibration	Safe/arm X axis Y axis Z axis		
Temperature and humidity	Safe/arm	16 Sept 1968	Sluggish arming. Detonators No. 1 and 2 armed intermittently. Both armed after several cycles
Shipboard vibration	Safe/arm X axis Y axis Z axis	20 Sept 1968	Electrical checkout was completed after several cycles; neither detonator armed at less than 20 psig
Salt spray	Safe/arm	7 Oct 1968	Sluggish arming (discussed in text)

Table H-9. Embedment Anchor Safe/Arm Device -- Unit 11.

Test	Posttest Checkout	Date	Remarks
Transportation vibration	Safe/arm X axis Y axis Z axis		
Temperature and humidity	Safe/arm	16 Sept 1968	Sluggish arming; arming indicated after 3 cycles
Shipboard vibration	Safe/arm X axis Y axis Z axis	20 Sept 1968	Electrical checkout all right. Detonator No. 2 armed at 16 psig; detonator No. 1 armed at 16 psig after having made 3 cycles.
Salt spray	Safe/arm	7 Oct 1968	Sluggish arming; open circuit at 20 to 25 psi (discussed in text)

Table H-10. Embedment Anchor Safe/Arm Device -- Unit 16.

Test	Posttest Checkout	Date	Remarks
Transportation vibration	Safe/arm	15 Aug 1968	Failed electrical checkout
	X axis	29 Aug 1968	Failed; arming slide jammed *
	Y axis		
	Z axis	15 Aug 1968	Passed electrical checkout
Shipboard vibration	Safe/arm	17 Sept 1968	Electrical checkout all right. Both detonators armed at 16 psig
Waterproofness	Safe/arm	20 Sept 1968	Passed

* The unit was disassembled and examined; the findings are discussed in text.

Table H-11. Embedment Anchor Safe/Arm Device -- Unit 17.

Test	Posttest Checkout	Date	Remarks
Transportation vibration	Safe/arm		
	X axis		
	Y axis		
	Z axis		
Shipboard vibration	Safe/arm	17 Sept 1968	Electrical checkout all right. Both detonators armed at 16-1/2 psig
Waterproofness	Safe/arm	20 Sept 1968	Passed

Table H-12. Embedment Anchor Safe/Arm Device -- Unit 18.

Test	Posttest Checkout	Date	Remarks
Transportation vibration	Safe/arm X axis Y axis Z axis		
Shipboard vibration	Safe/arm	17 Sept 1968	Electrical checkout all right, although detonator No. 2 showed sluggish arming. After third cycle, arming was normal at 17 psig
Waterproofness	Safe/arm	20 Sept 1968	Passed
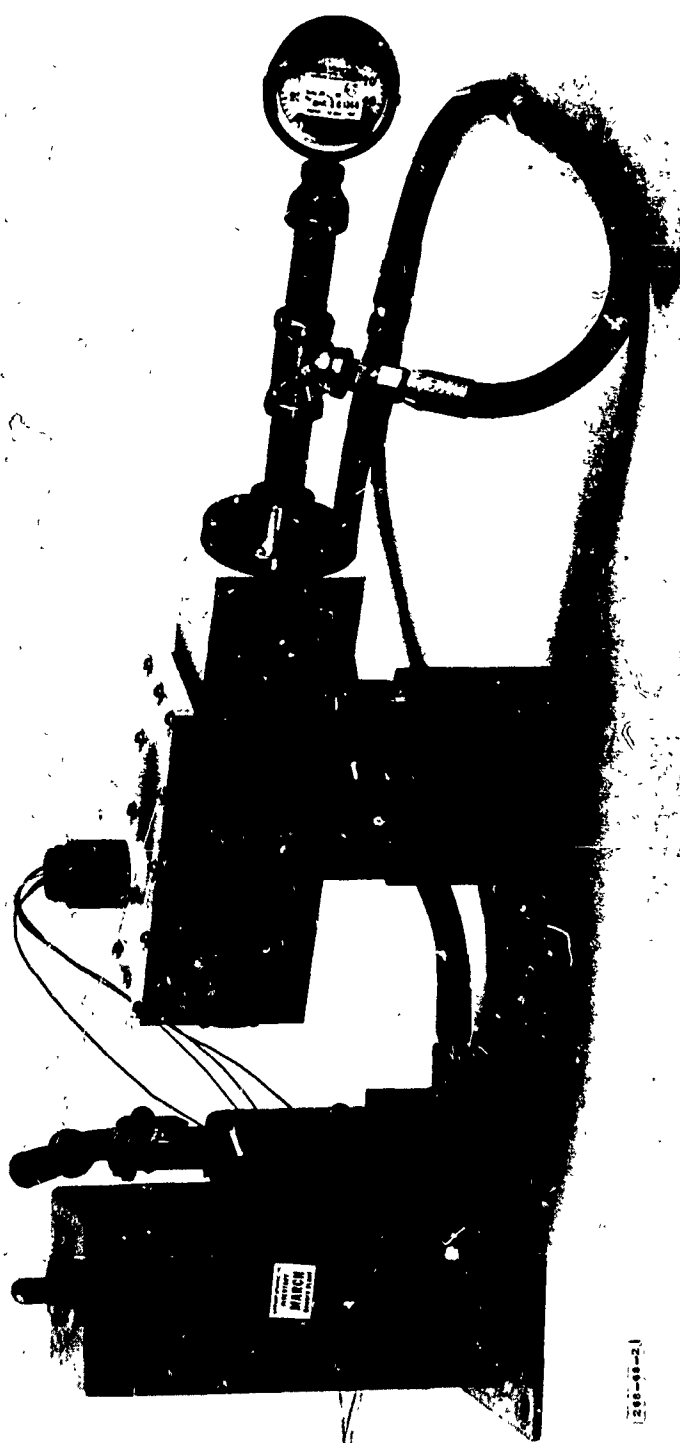
Figure H-2. Hydraulic Water Pump Setup.

Three units (Serial No. 7, 8, and 16) were selected for transportation vibration tests; each one of these units was tested in the sequence shown in Figure H-1.

At the end of the environmental and dynamic tests, two units (Serial No. 1 and 2) were tested for static detonator safety at high and low temperatures and two units (Serial No. 5 and 16) were tested for performance test firing, using Part No. 1215907 pigtail leads and witness plates.

H.6 TEST INSTRUMENTATION AND SETUP

H.6.1 Transportation Vibration

The transportation vibration testing was conducted on a Caldyne vibrator and the input vibration levels were controlled with an Endevco accelerometer system (Model No. 2213C, Serial No. GK06). (See Figure H-3 for a view of the safe/arm device (Serial No. 8) mounted on the vibration machine.)

H.6.2 Temperature/Humidity

The temperature/humidity test was conducted in a Missimer temperature chamber. The temperature and humidity were automatically controlled and graphically monitored for the duration of the test.

H.6.3 Salt Spray

The salt spray test was conducted in a Bemco salt spray chamber. The Ph and specific gravity of the salt spray solution was checked in the analytical laboratory before starting. The temperature was monitored on a temperature recorder and fallout was measured in a milliliter graduate.

H.6.4 Waterproofness

The waterproofness test was conducted with a pressure vessel filled with water containing an indicator agent, sodium fluoresceinate (uranin), and pressurized with gas. Standard pressure gages were used to record the pressure.

H-14
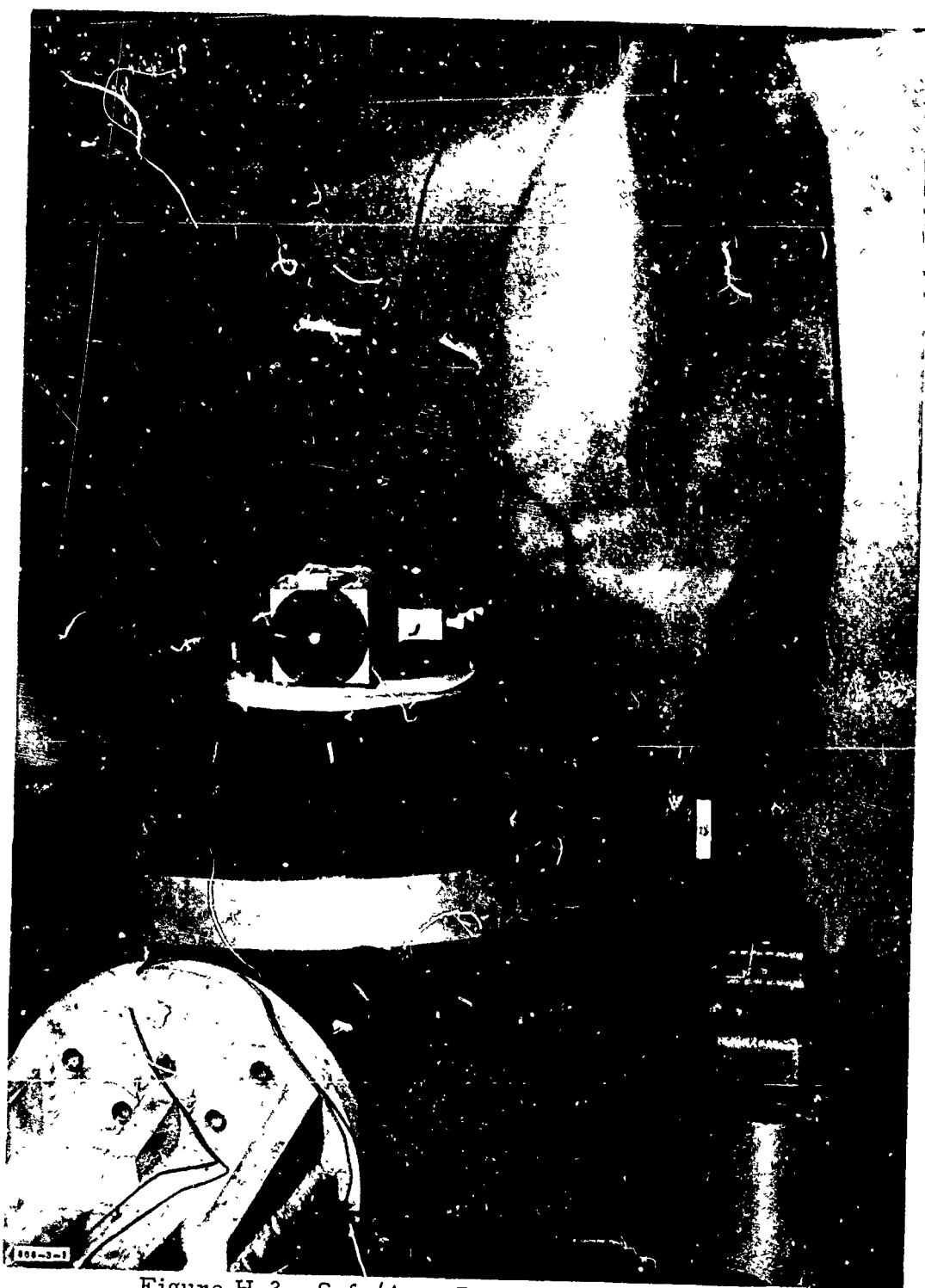
Figure H-3.   Safe/Arm Device Mounted on Vibration
Machine.

H-15

H.6.5 Shipboard Vibration

The shipboard vibration tests were conducted in the laboratory on a mechanical vibration machine. The vibration input levels of the vibration machine were determined with an Endevco accelerometer system and a visual displacement control.

H.6.6 Static Detonator Safety

To initiate the detonators in the safe position, it was necessary to rework the units used for the static detonator safety tests as follows: The curved portions of the slide assembly spring contacts were cut off and leads were soldered to the remaining portion. The leads were then passed through one of the holes normally occupied by one of the electrical contacts and soldered to their respective terminations on the RF filter assembly. Detonator firing was initiated from the anchor control panel through the cable assembly.

H.7 TEST RESULTS

H.7.1 Transportation Vibration (Test No. 104, MIL-STD-331)

The three test specimens were individually exposed to the transportation/temperature environments in accordance with Test No. 104, MIL-STD-331, Procedure I, while rigidly mounted to the head of the vibration machine. Three axes (X, Y, and Z) were tested (see Figure H-4).

The test specimens were tested in the following order: Unit No. 8 was tested at ambient temperature (+86° ± 18°F), Unit No. 16 was tested at high temperature (+160° +4°F), and Unit No. 7 was tested at low temperature (-65° +4°F), in accordance with the requirements set forth in Paragraph 5.1.1 of Test No. 104, MIL-STD-331. Refer to Table H-13 for test details.

The purpose of the transportation test is to check the safety and reliability of the fuze (safe/arm) under a wide variety of transportation conditions and at the aforementioned temperatures. A brief explanation of the vibration parameters is given in Table H-14. The total test duration is 24 hr plus the time spent at resonant frequencies. The fuzes must be safe and operable following the test.

H-16
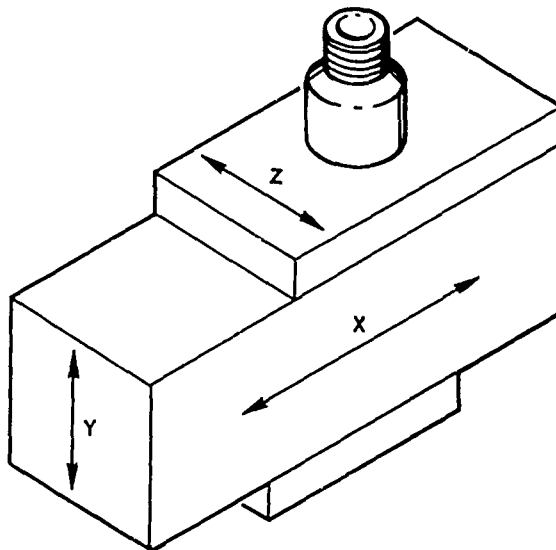
Figure H-4. Safe/Arm Vibration Axes.

Safe/arm device No. 8 was run through the various vibration steps at ambient temperature. Electrical functioning after each axis showed the safe/arm to be in good operational condition (see Table H-15).

Unit No. 16 was subjected to vibration at high temperature ($\pm 160°F$). After the first axis (Z), the unit passed the electrical functioning checks but, after the X axis, the unit failed to indicate an armed condition. The inclinometer functioned properly.

The top cover was removed and it was found that the brass jam nut attached to the stem of the bulkhead connector had backed off and dropped down over the wire bundle (see Figure H-5). The loose nut had vibrated and chafed against the lower threads of the bulkhead connector and against the shrinkfit tubing surrounding the soldered connections between the connector pins and leads. This resulted in the formation of a black residue in the top cavity, some of which probably entered the bore of the slide assembly. The bulkhead connector in the top plate was not loose and none of the lead wires were damaged. The residue was cleaned up and the nut potted in place with

H-17

Table H-13.   Transportation Vibration.

Serial No.	Date (1968)	Time Start	Time Stop	Temperature (°F)	Axis	Frequency (CPS) 5 to 500 ±3%	Amplitude DA 0.10 ±0.01	Amplitude G 2.0 ±0.2
8	31 July	1245		Ambient	Z	10 to 20	0.1	
			1405	Ambient	Z	20 to 60		2.0
		1415		Ambient	Z	20 to 60	0.1	
			1615	Ambient	Z	20 to 60		2.0
	1 August	0955		Ambient	Z	20 to 60	0.1	
			1025	Ambient	Z	20 to 60		2.0
		1040		Ambient	Z	60 to 500		5.0
			1140	Ambient	Z	500 to 60		5.0
		1240		Ambient	Z	500 to 60		5.0
			1400	Ambient	Z	500 to 60		5.0
		1430		Ambient	Z	500 to 60		5.0
			1630	Ambient	Z	500 to 60		5.0
				Ambient	Z	500 to 60		
	2 August	0847		Ambient	Z	500 to 60		5.0
			0907	Ambient	Z	500 to 60		5.0
		0907		Ambient	Z	500 to 60		5.0
			0937	Ambient	Z	500 to 60		5.0
		1430		Ambient	X	10 to 20	0.1	
			1630	Ambient	X	20 to 60		2.0
	5 August	0840		Ambient	X	20 to 60	0.1	2.0
			1000	Ambient	X	20 to 60	0	2.0
		1007		Ambient	X	60 to 500		5.0
			1127	Ambient	X	500 to 60		5.0
		1240		Ambient	X	500 to 60		5.0
			1400	Ambient	X	500 to 60		5.0
		1420		Ambient	X	500 to 60		5.0
			1620	Ambient	X	500 to 60		5.0
	6 August	0825		Ambient	X	500 to 60		5.0
			0855	Ambient	X	500 to 60		5.0
		0900		Ambient	X	10 to 20	0.1	
			0930	Ambient	X	20 to 60		2.0
		1015		Ambient	Y	10 to 20	0.1	
			1135	Ambient	Y	20 to 60		2.0
		1235		Ambient	Y	20 to 60	0.1	2.0
			1435	Ambient	Y	20 to 60	0.1	2.0
		1435		Ambient	Y	20 to 60	0.1	2.0
			1505	Ambient	Y	20 to 60	0.1	2.0
		1510		Ambient	Y	60 to 500		5.0
			1630	Ambient	Y	500 to 60		5.0
	7 August	0835		Ambient	Y	500 to 60		5.0
			1135	Ambient	Y	500 to 60		5.0
		1240		Ambient	Y	500 to 60		5.0
			1300	Ambient	Y	500 to 60		5.0
		1300		Ambient	Y	500 to 60		5.0
			1330	Ambient	Y	500 to 60		5.0
16	12 August	1300		+160	Z	10 to 20	0.1	
			1620	+160	Z	20 to 60		2.0
		1010		+160	Z	10 to 20	0.1	
			1040	+160	Z	20 to 60		2.0
		1045		+160	Z	60 to 500		5.0
			1145	+160	Z	500 to 60		5.0
		1235		+160	Z	500 to 60		5.0

Table H-13. Transportation Vibration (Continued).

Serial No.	Date (1968)	Time Start	Time Stop	Temperature (°F)	Axis	Frequency (CPS) 5 to 500 ±3%	Amplitude DA 0.10 ±0.01	Amplitude G 2.0 ±0.2
16			1645	+160	Z	500 to 60		5.0
	14 August	1010		+160	X	10 to 20	0.1	
			1145	+160	X	20 to 60		2.0
		1250		+160	X	20 to 60	0.1	
			1520	+160	X	20 to 60		2.0
		1525		+160	X	60 to 500		5.0
			2035	+160	X	500 to 60		5.0
	23 August	1600		+160	Y	10 to 20	0.1	
			1640	+160	Y	20 to 60		2.0
	26 August	1120		+160	Y	20 to 60	0.1	2.0
			1140	+160	Y	20 to 60	0.1	2.0
		1240		+160	Y	20 to 60	0.1	2.0
	.		1530	+160	Y	20 to 60	0.1	2.0
		1535		+160	Y	60 to 500		5.0
			1635	+160	Y	500 to 60		5.0
	27 August	1000		+160	Y	500 to 60		5.0
			114	+160	Y	500 to 60		5.0
		1240		+160	Y	500 to 60		5.0
			1510	+160	Y	500 to 60		5.0
7	15 August	1445		-65	Y	10 to 20	0.1	
			1835	-65	Y	20 to 60		2.0
		1840		-65	Y	60 to 500		5.0
			2040	-65	Y	500 to 60		5.0
	16 August	1040		-65	Y	500 to 60		5.0
			1140	-65	Y	500 to 60		5.0
		1240		-65	Y	500 to 60		5.0
			1450	-65	Y	500 to 60		5.0
	19 August	1240		-65	X	10 to 20	0.1	
			1630	-65	X	20 to 60		2.0
	20 August	1050		-65	X	60 to 500		5.0
			1130	-65	X	500 to 60		5.0
		1235		-65	X	500 to 60		5.0
			1635	-65	X	500 to 60		5.0
	21 August	1025		-65	X	500 to 60		5.0
			1055	-65	X	500 to 60		5.0
		1440		-65	Z	10 to 20	0.1	
			1640	-65	Z	20 to 60		2.0
	22 August	1000		-65	Z	20 to 60	0.1	2.0
			1135	-65	Z	20 to 60	0.1	2.0
		1240		-65	Z	20 to 60	0.1	2.0
			1255	-65	Z	20 to 60	0.1	2.0
		1300		-65	Z	60 to 500		5.0
			1640	-65	Z	500 to 60		5.0
	23 August	1015		-65	Z	300 to 60		5.0
			1125	-65	Z	500 to 60		5.0

Table H-14.   Vibration Schedule (Cycling Method).

Type	Frequency (cps)	Input Amplitude	Cycles*
Cycling	10 to 60 to 10	0.10 ±0.01-in. double amplitude or 2 ±0.2-g peak, whichever is the lesser	10
Cycling	60 to 5000 to 60	5 ±0.5-g peak	14
Resonance	As determined (would be single frequency points)	As indicated above in the specific frequency range	Dependent upon the number of resonant points

*Duration at each cycle and at the resonant frequency is 20 min. The total cycling test time in each axis is 8 hr, and the test time at resonant points is 20 min times the number of resonant frequencies.

Table H-15. Transportation Vibration Test Results.

Test	Axis	Date (1968)	Electrical Checkout	Remarks
Ambient temperature, * Unit No. 8	Z	2 August	Passed	
	X	6 August	Passed	
	Y	7 August	Passed	
High temperature, ** Unit No. 16	Z	15 August	Passed	
	X	15 August	Failed	Refer to explanation in text
	Y	27 August	Failed	Refer to explanation in text
Low temperature, *** Unit No. 7	Y	16 August	Passed	
	X	21 August	Passed	
	Z	23 August	See Remarks	Detonator No. 1 armed at 19 psi; detonator No. 2 armed at 19.5 psi

*Paragraph 5.1.1 b, MIL-STD-331.
**Paragraph 5.1.1 c, MIL-STD-331.
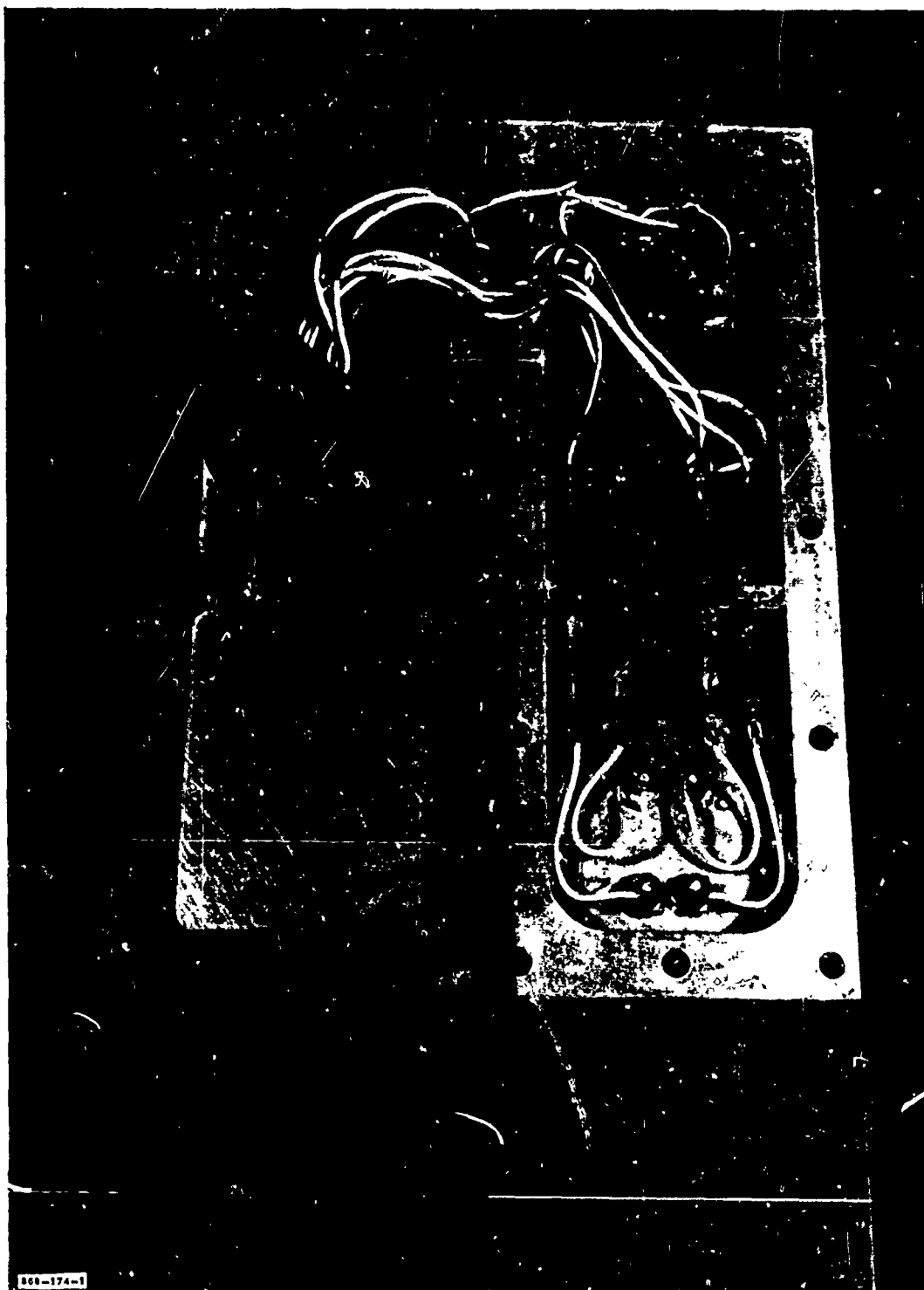***Paragraph 5.1.1 a, MIL-STD-331.

H-21

Figure H-5. Interior of Safe/Arm Device, Showing Loose
Jam Nut.

H-22

Armstrong A-1 adhesive. The slide assembly was removed and cleaned, the entire unit was reassembled and given an electrical checkout test, and testing was continued in the Y axis. Electrical checkout after completion of tests in the Y axis showed the inclinometer operated satisfactorily. However, the unit again failed to arm. Further investigation revealed that the solenoid operated properly but the slide failed to move under the specified pressure. Subsequent disassembly and investigation did not at first reveal why the locking balls would not disengage even though the solenoid plunger had been moved out of the way (released). Small burrs or nicks were observed on the edge of the housing bore radial groove where the locking balls normally engage. These burrs were removed and the unit was reassembled.

During preliminary operation of the solenoid and slide assembly, the slide would release one time but not the next. Further examination revealed that the 5/16-24 setscrew (Item 20, Drawing 1215513B) was too tight. After this screw was loosened 1-1/2 turns, the slide operated properly. The same condition had presumably existed after the first reassembly.

Based on the findings, the following conclusions have been reached. The reported malfunctioning (no-arm) after the X axis tests was also caused by a locked slide (no external means are available to determine if the slide has moved when using the adapter plate and hydraulic pump to operate the bellows assembly). When the unit was disassembled, the jam nut was found to have backed off, and foreign material was found in the slide cavity. It was thought that the unit had not armed because the foreign material had prevented good electrical contact. However, the nut, although loose, actually rested on the top of the two innermost RF filter cases on one side and on the bundle of wires on the other side and would in no way prevent the slide from arming or short any wires. Also, the amount of foreign material on the contacts was too small to prevent the unit from arming. Therefore, an armed indication would probably have occurred had the slide operated as intended.

The probable cause of the brass nut backing off is that the expansion factor for brass is larger than the expansion factor for the plastic composition of the bulkhead connector stem. At +160°F, the remaining friction between the nut and the stem was not sufficient to withstand the vibration forces. It is felt that this decrepancy can be rectified by potting the nuts in place or by equipping the nut with a locking device.

It should be noted that the other two units subjected to transportation vibration showed no sign of the jam nut backing off, although the nut on Units 9 and 11, which had been subjected to shipboard vibration, were slightly loose. Since Unit 16 had been worked on several times, it was decided to perform a leak

check on it before testing further; a leak was then found in the bellows assembly. After a new bellows assembly was installed, the unit passed the leak check satisfactorily. The leak in the bellows assembly is thought to be the result of examining and reworking this particular unit several times. It is assumed that the leak developed during this time because no water had leaked into the unit during the hydraulic arming checkout. Each time the slide is removed and reinstalled, the bellows assembly is rotated (twisted) and it is believed this repeated abuse caused the bellows to leak.

Unit 7 was subjected to vibration at low temperature (-65°F). The unit passed the electrical checkout tests after tests on both the Y and X axes, but electrical checkout after the Z axis showed that the unit did not completely arm at 18 psi as required. Detonator No. 1 armed at 19 psi and detonator No. 2 armed at 19.5 psi. Thus, in effect, this particular unit would not arm until it was approximately 43 ft below the surface of the water as opposed to 40 ft as specified. Upon disassembly of the unit, examination did not reveal any particular reason for the sluggish arming but it is thought that the dry lubricant sprayed inside the bore before assembly might have caked or produced some drag on the slide assembly. Lubricant could also have been deposited on the contacts, thus causing late arming. Also, the spring in this assembly might have been slightly stiffer and would not allow the slide to move to the armed position as soon as desired.

A bead of mercury approximately 1/32 in. in diameter was noticed in the top cavity next to the inclinometer switch. Microscopic examination of the inclinometer switch revealed a pinhole in the epoxy filling at the edge of the switch top plate. The mercury had presumably escaped through this hole. However, the amount of mercury lost was so minute it had not effected the inclinometer switch function. No other traces of mercury were found and it is believed that this siutation had no bearing on the sluggish arming condition. The defect was rectified by filling the pinhole with epoxy resin. The unit was then reassembled and an electrical checkout test performed which indicated that the unit operated properly.

The condition of the MDF leads in the safe/arm housing of the three devices tested was checked at random by removing the pipe plugs to see if the MDF had vibrated loose or if any explosive had loosened. In every case, the MDF was solid and intact.

H.7.2   Temperature/Humidity (Test No. 105, MIL-STD-331)

Four units (Serial No. 4, 8, 9, and 11) were exposed to temperature and humidity environments at the same time. Two complete 14-day JAN-STD temperature and humidity cycles were run, for a total of 28 days. The

basic 14-day JAN-STD cycle consists of cycling the devices nine times be-
tween the extremes of +160°F (95% relative humidity) and -65°F with
additional storage at +160°F (95% relative humidity) and -80°F. The safe/
arm units must be safe and operable following the test.

Visual examination of the units after testing showed that the appearance of
the safe/arm units had not been effected to any great degree. One unit
(Serial No. 9) showed some slight crazing of the paint on top of the cover
plate. Otherwise, no visual effects could be detected. Electrical check-
out indicated a sluggish arming condition, i.e., the arming was not as
positive as was desired. Upon arming, one detonator showed an armed
condition and the other an unarmed condition. Also, the meter on the control
panel did not show a complete null as would have been the case had a solid
contact (completed circuit) been made. Cycling of the slide back to a safe
position and then rearming would result in positive arming. See 'able H-16
for test results.

Table H-16. Temperature and Humidity
Test Results.

Serial No.	Date of Test	Remarks
4	16 September 1968	Sluggish arming. Detonator No. 1 armed intermittently; deton-ater No. 2 armed. Dirt or corrosion on contact springs
8	16 September 1968	Sluggish arming. Detonator No. 1 was 2.5 small divisions off; deton-ator No. 2 was 1.5 divisions off on control panel meter
9	16 September 1968	Sluggish arming. Detonators No. 1 and 2 armed intermittently. Both armed after several cycles
11	16 September 1968	Sluggish arming. Both detonators armed firmly after three cycles

As will be seen in investigations made after the units had undergone all
environmental tests, the basic causes of this sluggish arming condition were
(1) some caked lubricant plus oxidation on the slide assembly spring
contacts and (2) oxidation on the external pins on the bulkhead connector.

H-25

H.7.3   Salt Spray (Test No. 107, MIL-STD-331)

The two groups of test specimens (Serial No. 4, 8, 9, and 11 in Sequence 1
and Serial No. 2, 3, 5, and 7 in Sequence 2) were exposed to salt spray
environments at different intervals.   Units 2, 3, 5, and 7 started
tests on 29 July 1968, before any other tests.   Units 4, 8, 9, and 11 were
exposed to salt spray environments starting 26 September 1968, after first
having undergone temperature/humidity tests and shipboard vibration tests.

The salt spray test consisted of exposing bare safe/arm devices to salt
spray (fog) atmosphere for 48 hr to check operability and 96 hr to check
safety.

Examination and electrical checkout tests on Units 2, 3, 5, and 7 after 48
hr showed no detrimental effects on the safe/arm devices and all functioned
properly.   Some salt deposits (crystals) were evident around the outer edge
of the bellows flange.   No crazing or other defects were in evidence on the
painted surfaces or other areas.   Examination after 96 hr showed no additional
deterioration, and these units were considered to have passed the salt spray
requirements.

Examination and electrical checkout tests on Units 4, 8, 9, and 11 after 48
hr of salt spray exposure showed no resultant adverse effects, except that
these units showed slightly more salt deposits at the intersection of the bellows
flange and the safe/arm housing.   Removal of the deposits showed that some
corrosion had begun but was too minor to affect the safety or functioning of
the units.   One reason for these units being slightly more effected than the
first group was that the latter group had been subjected to temperature and
humidity tests before the salt spray tests, which might have started some
deterioration of the painted surface at the junction of the bellows flange and
the housing.   Also, since these units had undergone transportation vi-
bration test, some paint had chipped away or been scratched in places, such as
around the mounting holes for the holddown bolts.   Consequently, some slight
corrosion had started at some of these areas.   Again, however, the effect
was minimal and would in no way be detrimental to the safety or functioning
of the unit.   The crimping sleeves on the lanyard assembly (Part No.
1215656-1) showed some discoloration and slight salt deposits which, again,
were too minor to affect performance in any way.

Electrical checkout was performed as thoroughly as possible on Units 4, 8,
9, and 11 after 48 hr because they were expected to exhibit the same sluggish
arming conditions after this test as after the temperature and humidity tests.
It should be noted that these units had not been opened up or reworked in any

way. Table H-17 gives details of these checkout tests. The needle deflections indicate that a certain amount of resistance exists in the circuit but not that the units would not function. A 1.5-ohm resistor placed across Pins 1 and 2 and 3 and 4, respectively, at the end of the cable assembly showed a meter needle deflection of 3-1/2 small graduations. As was found by using Freon degreaser on the external pins of the bulkhead connector, some of the resistance in the circuit could be eliminated in some cases and not in others. The all-fire firing current for the D3A2 detonator is 5.0 amp and the minimum fire current (not recommended) is 4.0 amp. The current applied to the detonators is 10 amp. (The system resistance is 3.2 ohms and the voltage 32 vdc; consequently, amperage = $I = 32/3.2 = 10$.) Therefore, assuming a needle deflection of 3.5 small divisions, an additional resistance of 1.5 ohm has been picked up. Thus, the current applied to the contacts is $I = 32/3.2 + 1.5 = 32/4.7 = 6.8$ amp, which is well above the 5.0-amp recommended firing current.

By setting 5.0 amp as the minimum allowed, the resistance could be $R = 32/5 = 6.4$ ohms. By subtracting the system resistance of 3.2 ohms, a total contact buildup of $6.4 - 3.2 = 3.2$ ohms could be tolerated. Inserting a 3.2-ohm resistor at the end of the firing cable produced a needle deflection of 6.5 small divisions. By setting this as the criterion it can be seen that the units in question actually would pass. The only exception was on Unit 11, which at one time showed an open circuit at 20 psi and later at 25 psi. It is thought that this condition was caused by the head of the contact pin riding up and slightly over the top of the contact spring, at which time either oxidation or foreign material on the contact surface prevented electrical contact. It is believed that the problems can be eliminated by changing the shape of the contact pins to a pointed end so that the contact pin will pierce the oxidation as it rides up on the contact spring. This change is shown in Figure H-6.

Units 4, 8, 9, and 11 were disassembled and examined. No detrimental effects could be noticed except as follows:

Unit	Condition
4	Top cavity clean. Very little caked lubricant on slide and almost none on spring contacts. Spring contacts dull and oxidized. No dirt on ends of contact pins.
8	Top cavity clean. Slide had some gray material close to thrust washer and on edges of spring contacts. This material was a combination of caked lubricant and some aluminum dust created by thrust washer vibration. Spring contacts dull and oxidized. No dirt on ends of contact pins.

H-27

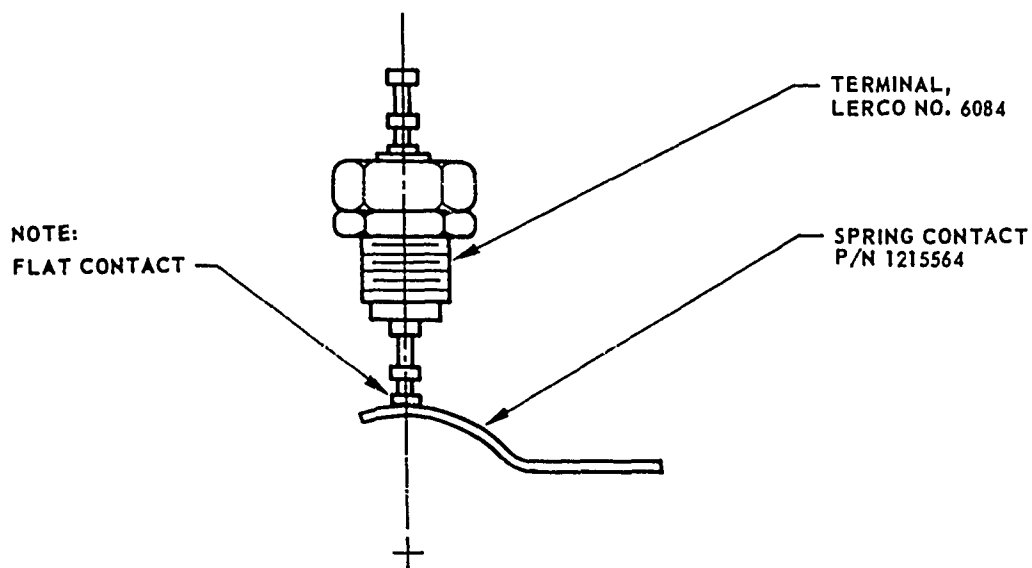Table H-17. Electrical Checkout of Units 4, 8, 9, and 11 After Completion of All Environmental Tests.

Unit (Serial) No.)	Gage Pressure (psi)	Detonator No.	Panel Meter Deflection	Remarks
9	18	1	1-1/2 lg *	First arming; inclinometer functioned properly
		2	2 lg	
	18	1	5 sml	Second arming
		2	2 sml	
	19	1	1-1/2 sml	
		2	2 sml	
	20	1	1-1/2 sml	
		2	3-1/2 sml	
	22	1	1-1/2 sml	
		2	3-1/2 sml	
4	18	1	1/2 lg	First arming; inclinometer functioned properly
		2	1-1/2 sml	
	19	1	1/2 sml	
		2	2 sml	
	18	1	3 sml	Second arming
		2	1 sml	
	20	1	1-1/2 sml	
		2	2 sml	
	18	1	5 sml	Freon sprayed on bulkhead pins **
		2	1 sml	
	19	1	OK	
		2	1/2 sml	
8	18	1	3/4 lg	First arming; inclinometer functioned properly
		2	1 sml	
	19	1	3 sml	
		2	1-1/2 sml	
	20	1	1 sml	
		2	1 sml	

Table H-17. Electrical Checkout of Units 4, 8, 9, and 11 After Completion of All Environmental Tests (Continued).
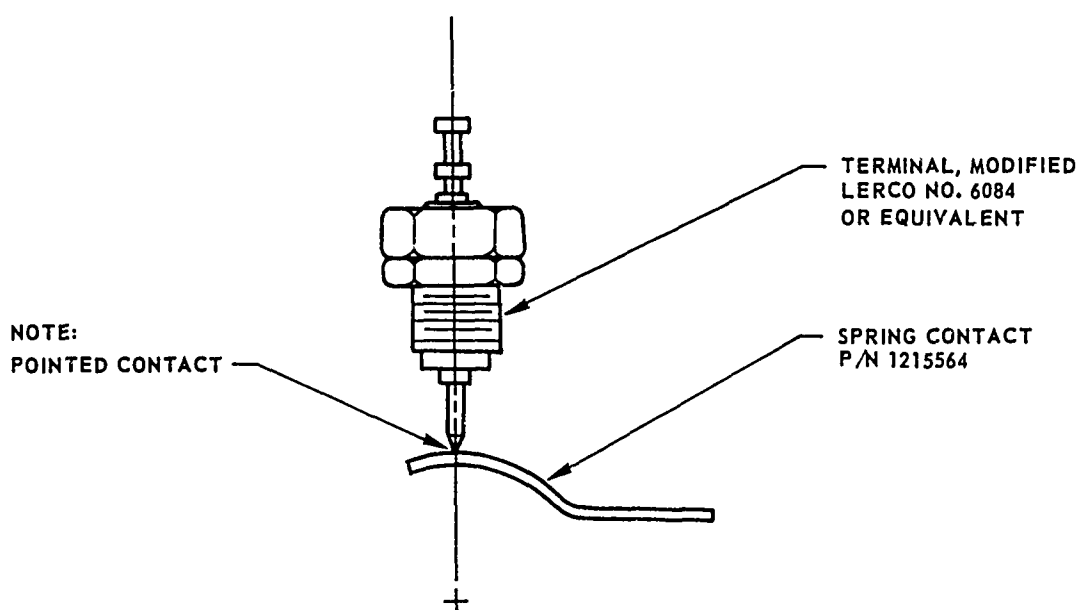
Unit (Serial No.)	Gage Pressure (psi)	Detonator No.	Panel Meter Deflection	Remarks
11	18	1	1 sml	Second arming
		2	1 sml	
	18	1	1-1/2 sml	Freon sprayed on bulkhead pins
		2	1 sml	
	19	1	1-1/2 sml	
		2	1-1/2 sml	
	18	1	2 sml	Inclinometer functioned properly
		2	2 sml	
	19	1	1-1/2 sml	
		2	2 sml	
	20	1	Open	
		2	Open	
	18	1	OK	
		2	1 lg	
	20	1	1 sml	
		2	3/4 lg	
	18	1	3/4 sml	Freon sprayed on bulkhead pins
		2	3-1/2 sml	
	19	1	6 sml	
		2	4-1/2 sml	
	20	1	OK	
		2	1 sml	
	25	1	Open	
		2	Open	

* lg = large divisions on panel meter;
   sml = small divisions on panel meter.

** MS-180 Freon TF® Degreaser.

TERMINAL,
LERCO NO. 6084

SPRING CONTACT
P/N 1215564

NOTE:
FLAT CONTACT

EXISTING ARRANGEMENT

TERMINAL, MODIFIED
LERCO NO. 6084
OR EQUIVALENT

SPRING CONTACT
P/N 1215564

NOTE:
POINTED CONTACT

RECOMMENDED ARRANGEMENT

Figure H-6.   Contact Pin Configuration Change.

Unit	Condition
9	Top cavity clean. Slide and edges of contacts had slight amount of caked lubricant. Otherwise all right. Brass nut slightly loose.
11	Top cavity clean. Brass nut had started to back off (approximately 1 turn). Spring contacts dull and oxidized, with some white flakes of dry lubricant. No dirt on ends of contact pins.

Some of the loose, caked lubricant in the bore of the safe/arm units was wiped off with Kimwipes and the units were reassembled. After reassembly, the units checked out as shown in Table H-18.

Table H-18. Electrical Checkout of Units
4, 8, 9, and 11 After Disassembly and
Cleanup.

Unit (Serial No.)	Detonator No. 1	Detonator No. 2	Inclinometer
4	Satisfactory	1 sml	Satisfactory
8	1 sml	1 sml	Satisfactory
9	Satisfactory	1/2 sml	Satisfactory
11	Satisfactory	Satisfactory	Satisfactory

H. 7.4 Shipboard Vibration (Type 1, MIL-STD-331)

All three groups of test specimens were subjected to shipboard vibration, Type I (environmental vibration) in accordance with the requirements of MIL-STD-167. The two groups of test specimens (Serial No. 1, 16, 17, and 18 of Sequence 2 and Serial No. 2, 3, 5, and 7 of Sequence 3) were scheduled so that they could be vibration tested at the same time; the test fixture on the vibration machine can accommodate eight units at one time. The group from Sequence 1 (Serial No. 4, 8, 9, and 11) were tested by themselves.

Type I environmental vibration first requires searching for resonances at frequencies of 5 (or the lowest attainable frequency) to 33 cps and an amplitude of 0.010 in. and then performing a 2-hr endurance test in three separate axes (X, Y, and Z). The endurance test is performed at the resonance frequency or, if none is found, at 33 cps.
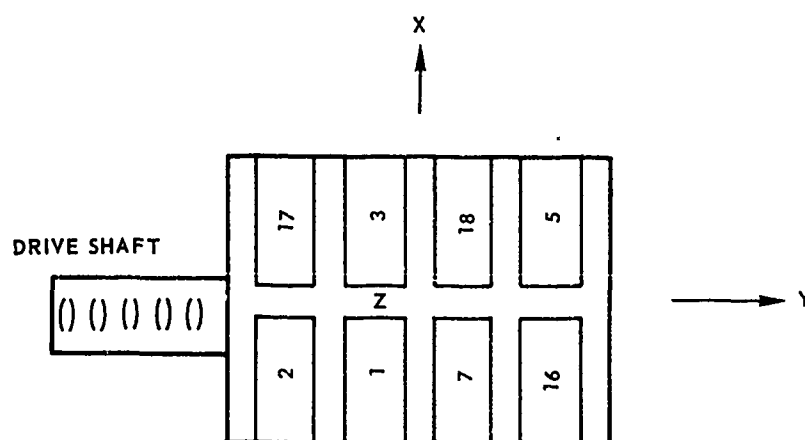
H.7.4.1   Safe/Arm Shipboard Vibration Data -- X Axis

An exploratory vibration search was performed; no resonant points were found.

A variable frequency test was performed as follows:

RPM	CPS	RPM	CPS	RPM	CPS
300	5	900	15	1500	25
360	6	960	16	1560	26
420	7	1020	17	1620	27
480	8	1080	16	1680	28
540	9	1140	19	1740	29
600	10	1200	20	1800	30
660	11	1260	21	1860	31
720	12	1320	22	1920	32
780	13	1380	23	1980	33
840	14	1440	24		

The endurance test was begun on 11 September 1968 and performed for 1/2 hr, at which time testing was halted. The test was resumed on 12 September and performed for 1-1/2 hr, to completion.
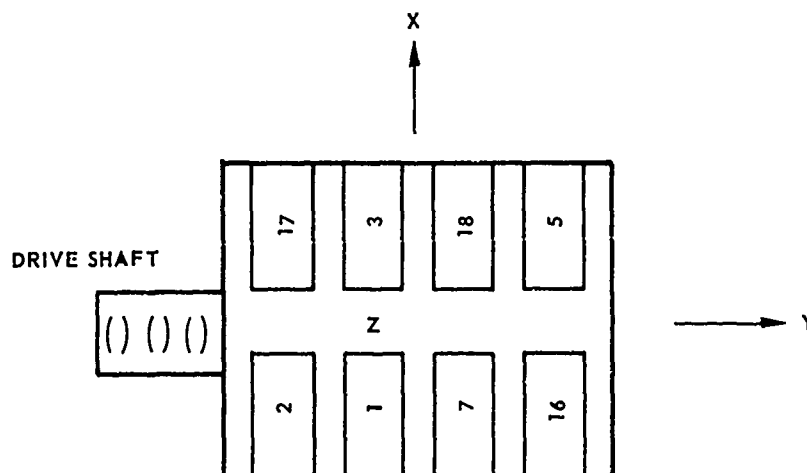

PLACEMENT OF UNITS ON TABLE

H.7.4.2   Safe/Arm Shipboard Vibration Data -- Z Axis

An exploratory vibration search was performed; no resonant points were found.

A variable frequency test was performed as follows:

RPM	CPS	RPM	CPS
300	5	1200	20
360	6	1260	21
420	7	1320	22
480	8	1380	23
540	9	1440	24
600	10	1500	25
660	11	1560	26
720	12	1620	27
780	13	1680	28
840	14	1740	29
900	15	1800	30
960	16	1860	31
1020	17	1920	32
1080	18	1980	33
1140	19		

The endurance test was begun on 12 September 1968 and performed for 1-1/2 hr, at which time testing was halted.   Testing was resumed on 13 September and performed for 1/2 hr, to completion.
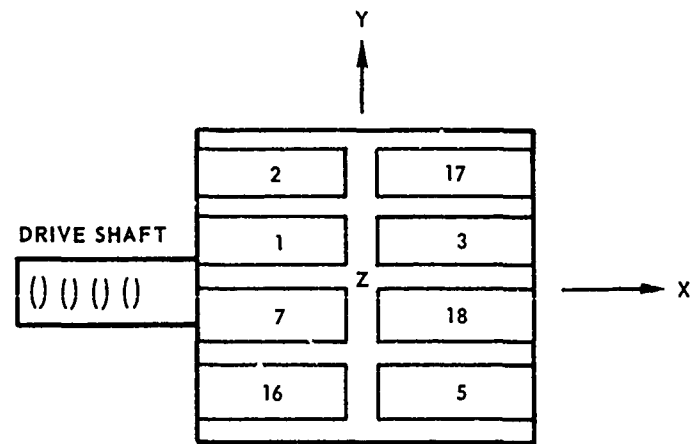

PLACEMENT OF UNITS ON TABLE

H-33

H.7.4.3 Safe/Arm Shipboard Vibration Data -- Y Axis

An exploratory vibration search was performed; no resonant points were found.

A variable frequency test was performed as follows:

RPM	CPS	RPM	CPS
300	5	1200	20
360	6	1260	21
420	7	1320	22
480	8	1380	23
540	9	1440	24
600	10	1500	25
660	11	1560	26
720	12	1620	27
780	13	1680	28
840	14	1740	29
900	15	1800	30
960	16	1860	31
1020	17	1920	32
1080	18	1980	33
1140	19		

An endurance test was performed; results are presented elsewhere in this appendix.
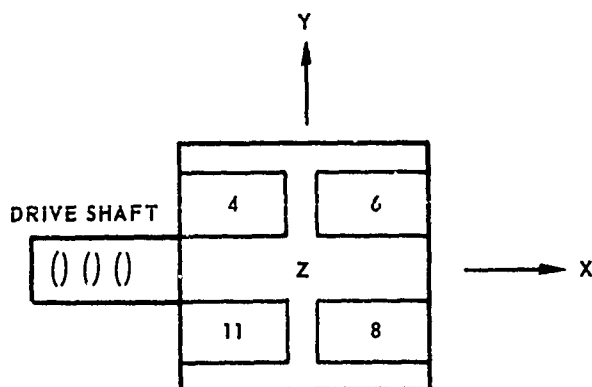

PLACEMENT OF UNITS ON TABLE

H.7.4.4 Safe/Arm Shipboard Vibration Data, After Temperature
and Humidity Tests -- Y Axis

An exploratory vibration search was performed; no resonant points were
found.

A variable frequency test was performed as follows:

RPM	CPS	RPM	CPS
300	5	1200	20
360	6	1260	21
420	7	1320	22
480	8	1380	23
540	9	1440	24
600	10	1500	25
660	11	1560	26
720	12	1620	27
780	13	1680	28
840	14	1740	29
900	15	1800	30
960	16	1860	31
1020	17	1920	32
1080	18	1980	33
1140	19		

An endurance test was performed; results are presented elsewhere in
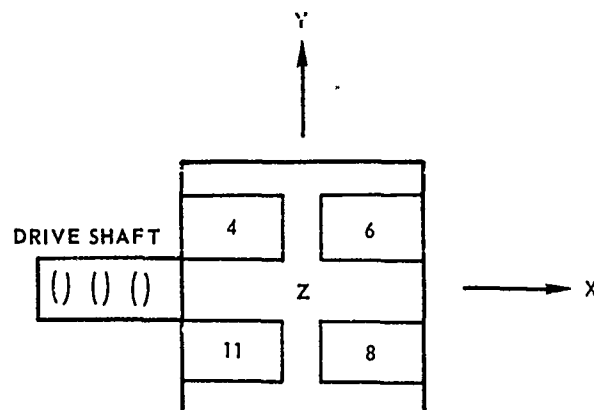this appendix.

PLACEMENT OF UNITS ON TABLE

H-35

H.7.4.5   Safe/Arm Shipboard Vibration Data, After Temperature
and Humidity Tests -- Z Axis

An exploratory vibration search was performed; no resonant points were
found.

A variable frequency test was performed as follows:

RPM	CPS	RPM	CPS
300	5	1200	20
360	6	1260	21
420	7	1320	22
480	8	1380	23
540	9	1440	24
600	10	1500	25
660	11	1560	26
720	12	1620	27
780	13	1680	28
840	14	1740	29
900	15	1800	30
960	16	1860	31
1020	17	1920	32
1080	18	1980	33
1140	19		

An endurance test was performed; results are presented elsewhere in
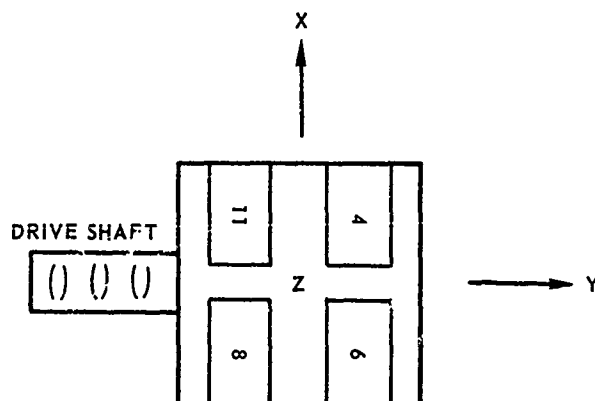this appendix.

PLACEMENT OF UNITS ON TABLE

H-36

H.7.4.6 Safe/Arm Shipboard Vibration Data, After Temperature and Humidity Tests -- X Axis

An exploratory vibration search was performed; no resonant points were found.

A variable frequency test was performed as follows:

RPM	CPS	RPM	CPS
300	5	1200	20
360	6	1260	21
420	7	1320	22
480	8	1380	23
540	9	1440	24
600	10	1500	25
660	11	1560	26
720	12	1620	27
780	13	1680	28
840	14	1740	29
900	15	1800	30
960	16	1860	31
1020	17	1920	32
1080	18	1980	33
1140	19		

An endurance test was performed; results are presented elsewhere in this appendix.

PLACEMENT OF UNITS ON TABLE

Electrical checkout of Units 1, 16, 17, and 18 of Sequence 2 and Units 2, 3, 5, and 7 of Sequence 3 showed that the units operated satisfactorily after the shipboard vibration tests.

Electrical checkout of Units 4, 8, 9, and 11 of Sequence 1 after the shipboard vibration test showed the units exhibited the same sluggish arming tendencies that were found after the units had been exposed to the temperature/humidity tests. It was therefore concluded that the units had not suffered any damage as a result of the shipboard vibration tests.

H.7.5 Waterproofness (Test No. 108, MIL-STD-331)

Units 1, 16, 17, and 18 were all subjected to the waterproofness test at the same time. This test consists of immersing the safe/arm devices for 1 hr in a solution of sodium fluoresceinate (uranin) at a pressure of approximately 15 psi gage and a temperature of 70°F, and subsequently examining the disassembled fuze under ultraviolet light for evidence of water entry. There must be no evidence that any water has entered the fuzes, and the fuzes must be safe and operable following the test. Examination of the fuzes indicated that no water had entered the fuze cavities and the fuzes therefore passed the waterproofness test.

H.7.6 Static Detonator Safety (Test No. 115, MIL-STD-331)

Units 1 and 2 were tested for static detonator safety in accordance with the procedures of Test 115, MIL-STD-331. This test consists of firing one or more explosive components in sample safe/arm fuzes, checking the effectiveness of the explosive train interrupter, and determining whether there is ejection of parts, deformation, or shattering that might result in unsafe conditions. Tests were conducted at both high and low temperature ($+160^\circ$F and -65°F, respectively).

To conduct these tests, it was necessary to modify the safe/arm units so the detonators could be fired with the slide assembly in the safe position (Paragraph H.6.6). Both detonators were initiated at the same time to simulate "worst conditions."

Unit 1 was fired at $+160^\circ$F. To reach this temperature, the safe/arm was placed in an oven and stabilized for 2 hr. Unit 2 was fired at -65°F, which was reached by placing the unit in a low-temperature chamber for 2 hr.

Only a slight snap or cracking sound could be heard when the units were fired. There was no heat buildup or observable gas or smoke. Subsequent disassembly and examination revealed the following:

a. When the top cover bolts were loosened, trapped combustion gases escaped with a hissing sound.

b. A strong gas smell was present.

c. Soot was present at the holes at the top cavity.

d. The slides were stuck and had to be forced out.

e. The side of the slides had bulged at the detonator locations.

f. The housing bore was severely dented (cavities) at the detonator locations.

g. The ends of the MDF leads butting into the safe/arm bore were intact; no scorching or charring was observed. No burning or melting of the leads had occurred, but some smudge or soot was evident on the ends of the MDF.

h. There was no deformation or shattering of the safe/arm external surfaces.

The detonator safety tests at high and low temperatures were considered successful. It should be noted that during the development phase of this program, a detonator safety test was conducted on one safe/arm assembly at ambient temperature. The test conditions and results duplicated the previously described test. The safe/arm device therefore met the static detonator safety requirements at high, ambient, and low temperatures.

H.7.7 Performance Test Firing

Units 5 and 16 were tested for performance test firing. Each unit had three pigtail assemblies (Part No. 1215907 N/C) attached to it, which, in turn, were butted up against 1/4- by 1-1/4- by 1-1/4-in. aluminum witness plates in order to verify the explosive performance characteristics. The units were armed by using the hydraulic water pump setup shown in Figure H-2),

H-39

with the detonators initiated from the firing control panel as in the previous tests. Both units performed as intended, with good propagation of the explosive leads and good output at the end of the pigtail leads.

H.8 RECOMMENDATIONS

Although the existing design was proved feasible, it is recommended that the following minor modifications be made on future safe/arm devices to correct some of the undesirable features encountered during the prequalification test program.

The shape of the contact pins should be changed to that shown in Figure H-6. This should allow the contact pin to penetrate any oxidation or foreign material on the spring contacts.

The use of dry fluorocarbon lubricant inside the bore should be eliminated. It is felt that this lubricant does more harm than good, and the clearances between the slide assembly and the bore are such that a nonlubricated condition can be tolerated.

The jam nut on the bulkhead connector should either be potted in place or equipped with some type of locking device that will prevent it from vibrating loose under extreme temperature conditions.

The type of material used in the gasket at the top cover (Part No. 1215636-1) should be changed. During assembly and reassembly, it was found extremely difficult to effect a good seal at this point (a leakage rate of less than 10^{-6} cc/sec of helium was sought). With the use of a better RF-type of gasket material at this point, less time would be required in assembling and checking out the unit.

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
Aerojet-General Corporation, Ordnance Division Research & Development Downey, California 90241	Unclassified
	2b. GROUP

3 REPORT TITLE

PROPELLANT-ACTUATED EMBEDMENT ANCHOR

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final   August 67 - November 68

5 AUTHOR(S) (First name, middle initial, last name)

Thomason, R. A.
Bucella, F. J.
Lindberg, E. I.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
November 1968	217	0

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
N62399-68-C-0002	
b. PROJECT NO.	3324-01(01)FP
56-004	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	CR 69.026

10. DISTRIBUTION STATEMENT

Each transmittal of this document outside the agencies of the U. S. Government must have prior approval of the U. S. Naval Civil Engineering Laboratory

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
Contracted by: Naval Civil Engineering Laboratory Port Hueneme, California 93041	Supervisor of Salvage Naval Ships System Command Washington, D. C. 20360

13. ABSTRACT

This report contains a review of the results of an engineering, development, and manufacturing program for the development of a propellant-actuated embedment anchor. The objective of the program was to provide a prototype anchor system suitable for marine salvage operations. Calculations and engineering discussions are presented to support the design concept and certain specific components contained in the system. Test results are reviewed to define the demonstrated performance capability of the anchor in a variety of sea-floor compositions. Numerous photographs and drawings are included to illustrate the various anchor system components and to document the development test operations. Several appendixes are included to define specific test procedures, some of which are applicable to a general, future proof-test and evaluation program.